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Contractor's Report to the Board

Life Cycle and Market Impact Assessment of Noncombustion Waste Conversion Technologies

July 2004

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RTI International

INTEGRATED WASTE MANAGEMENT BOARD

Zero Waste—You Make It Happen!

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Table of Contents

List of Figures

List of Tables

Executive Summary

Background

New technologies to convert organic and plastic wastes to fuels and electricity, termed conversion technologies, are rapidly emerging. The California Integrated Waste Management Board (CIWMB) recognizes that the existing recycling and composting markets may not be sufficient. CIWMB is interested in exploring the potential for conversion technologies to provide a market for wastes that otherwise would be disposed.

Assembly Bill 2770 (Matthews, Chapter 740, Statutes of 2002) requires the CIWMB to prepare a report on noncombustion conversion technologies describing and evaluating their potential market and life cycle environmental impacts. The CIWMB awarded a contract to an RTI International[*] (RTI) team to perform this work. RTI managed the project and was the lead on the life cycle assessment.

The National Renewable Energy Laboratory prepared a materials and energy balance for selected conversion technologies and assisted RTI with the life cycle assessment. Hilton, Farnkopf & Hobson was the lead on the market impact assessment. Boisson & Associates coordinated public input and provided advice and assistance related to study design and presentation.

Separate from this study, the CIWMB contracted for a concurrent effort by the University of California at Riverside (UCR) and the University of California at Davis (UCD) to conduct a comprehensive technical evaluation of alternative conversion technologies. This report addresses issues relating primarily to technical feasibility and potential environmental impacts of these technologies.

Study Goals

This study addresses two primary questions:

1. What are the life cycle environmental impacts of conversion technologies and how do these compare to those of existing MSW management practices?
2. What are the economic, financial, and institutional impacts of conversion technologies on recycling and composting markets?

These questions are addressed in two distinct report sections, a *Life Cycle Assessment* and a *Market Impact Assessment*, respectively. The goal of the study is to better understand the range of impacts and the potential tradeoffs of using conversion technologies as alternatives to existing MSW management practices. It is not intended to make definitive conclusions about conversion technologies. The emphasis of the study is on conversion technologies as management alternatives for the post-recycling, unrecovered portion of the MSW stream, which is otherwise disposed in landfills.

Process for Conducting the Study

For approximately four years, the CIWMB has been examining noncombustion conversion technologies with the potential to consume materials currently disposed in landfills and convert them into energy, alternative fuels, and other industrial products. Prior to beginning research,

[*] RTI International is a trade name of Research Triangle Institute.

detailed technical memoranda were prepared describing the study methodologies. The draft methodologies were discussed at a focus group meeting hosted by the CIWMB in Sacramento on August 11, 2003, and circulated to a peer review group. They were subsequently revised based on input received. Preliminary findings from the life cycle assessment and the market impact assessment were circulated to peer reviewers and were also discussed at a workshop on April 15, 2004. Further revisions and analysis were conducted after this review.

Hypothetical Conversion Technology Development Scenario

This study analyzes the impacts of one particular hypothetical scenario for the development of conversion technologies in California. This scenario, defined by CIWMB for this study, includes the siting of 12 facilities using three specific technologies in two regions over a period of seven years. We focused the study in this way because of the uncertainty about how conversion technologies might actually be developed in practice.

Selected Conversion Technologies

Three conversion technologies were selected for study. They were chosen because municipalities in California have shown particular interest in them, as evidenced by requests for information. The technologies were seen as being commercial-ready based on research conducted prior to the start of this project, and data describing the technologies were relatively available.

Below are the selected conversion technologies:

Concentrated Acid Hydrolysis—In acid hydrolysis, an acid is used to convert carbohydrates from organic wastes into five- and six-carbon sugars that can be fermented into ethanol or other useful products. An example would be using sulfuric acid to convert cellulose and hemicellulose from yard and wood wastes.

High (that is, greater than 90 percent) conversions of carbohydrates are possible, and either concentrated or diluted acid can achieve the hydrolysis. The concentrated acid process was selected for this study because it is closer to commercialization than the dilute acid or enzymatic process. Two companies, Arkenol and Masada OxyNol,™ LLC, are currently commercializing concentrated acid technology. Neither company has a commercial facility, but Masada was awarded an air permit for a facility to process 230,000 tons per year (tpy) of MSW and other wastes in Middletown, NY.

Gasification—In gasification, feedstock is converted to a synthetic gas (syngas), primarily carbon monoxide (CO) and hydrogen (H_2), in an oxygen-deficient atmosphere. Gasification is endothermic and requires a heat source, such as syngas combustion, char combustion, or steam. The primary product of gasification, syngas, can be converted into heat, power, or chemical products, or used in fuel cells.

At least seven technologies were identified as commercially proven on a large scale and were considered for inclusion in this study. The State of California's definition of gasification specifies no oxygen introduction to the gasification process. This definition is very narrow and differs from the general definition of gasification in the companion *University of California Conversion Technology Evaluation Report*. The majority of existing gasification technologies include some oxygen introduction. Only the Brightstar Environmental Solid Waste Energy Recycling Facility (SWERF) technology met the State's definition and was included for further study.

Catalytic Cracking—In thermal cracking (for example, pyrolysis) or catalytic cracking, waste plastics are converted into liquid and gaseous fuels. The addition of catalysts lowers the reaction time and temperature and can increase the selectivity of the products, but catalysts are generally expensive. H.SMARTech, Inc., which runs the largest catalytic cracking plastics-recycling plant in the world in Zabrze, Poland, formed Plastics Energy, LLC, to build a 50 ton per day (expected to expand to 100 tpd) facility in Kings County, California, by the end of 2004. Other companies (for example, Ozmotech) have plastics pyrolysis facilities in Europe and Asia.

Table ES-1 summarizes the technical feasibility, feedstock compatibility, facility integration, environmental burdens, and technology development status for each technology. None of these facilities currently exist in the United States for treating MSW.

Table ES-1. Summary of Conversion Technology Features

Feature	Acid Hydrolysis	Gasification	Catalytic Cracking
Technical feasibility	Yes	Yes	Yes
Feedstock constraints	Carbohydrate fraction	Carbohydrate fraction, lignin, plastics	Polyolefin plastic only
Possible product(s)	Ethanol Electricity, steam, lignin Gypsum	Syngas Electricity Heat	Low sulfur diesel Electricity
Environmental Impacts Air Water Solid	Combustion emissions On-site wastewater treatment (WWT) required Ash, char	Combustion emissions Minimal Ash and char	Combustion emissions Minimal rinse water Spent catalyst
Commercial Status	No commercial facilities Masada OxyNol received air permit for a NY facility; construction scheduled for 2004	Numerous commercial facilities (none for MSW in the United States) Large demonstration facility in Australia, closed in 2003	Facility in Poland Kings County, Calif.: construction scheduled for 2004 Several plastic pyrolysis plants in Europe and Asia
Model Technology Vendor	Masada	Brightstar Environmental	Plastics Energy, LLC

Assumed Geographic Locations and Development Rate

The San Francisco Bay Area and the Greater Los Angeles Area were selected for study because a large percentage of California's MSW is generated and processed within them. The conversion technology facilities were assumed to begin operating in both regions at varying capacities from the base year of 2003 to 2010, as summarized below and in Table ES-2.

2003 (Base Year)

- Three 500 dry tpd acid hydrolysis facilities in each region (1,500 dry tpd total).
- Four 500 dry tpd gasification facilities in each region (2,000 dry tpd total).
- One stand-alone, 50 dry tpd catalytic cracking facility in each region.

Years 2004 to 2010

- One additional 500 dry tpd gasification plant built in each region in the year 2005.
- Two additional 500 dry tpd acid hydrolysis plants built in each region in 2007.
- One additional 500 dry tpd gasification plant built in each region in 2010.

Table ES-2. Facility Configurations, 2003 to 2010, dry tons per day

	2003	2004	2005	2006	2007	2008	2009	2010
Acid Hydrolysis	1,500	1,500	1,500	1,500	2,500	2,500	2,500	2,500
Gasification	2,000	2,000	2,500	2,500	2,500	2,500	2,500	3,000
Catalytic Cracking	50	50	50	50	50	50	50	50
TOTAL	3,550	3,550	4,050	4,050	5,050	5,050	5,050	5,550

For this study, we assumed that conversion technology facilities would be handling waste material that would otherwise be disposed in landfills. Because each conversion technology facility can only accept certain materials in its process, each facility employs up-front material separation activities similar to those found in a mixed-waste MRF (with the exception of a few pieces of specialty equipment, such as autoclaves and floatation separation systems).

Limitations of This Study

Identifying and evaluating every possible outcome of any technology is an impossible task. This is the first study to attempt to comprehensively analyze environmental and market impacts of conversion technologies. For this reason, it was necessary to limit the analysis to one particular hypothetical growth scenario.

The conversion technologies studied do not yet exist, nor do they operate at commercial scales in the United States. Considerable uncertainty exists as to where the conversion technologies would be located and which specific technologies would be built. Questions about how the conversion technologies would operate, what feedstocks they would accept, and what their environmental and market impacts would be are also present.

Furthermore, conversion technologies and proposed facilities are evolving rapidly, and much of the information regarding this evolution is proprietary. The study approach is based on reasonable and conservative assumptions about conversion technologies. The study offers order-of-magnitude assessments of the potential impacts of the selected conversion technologies on the environment and recycling and composting markets.

We do not attempt to make predictions about the success or actual environmental and market impacts of specific conversion technology facilities. Additional limitations related to the life cycle assessment and market impact assessment are presented following the findings for each.

Methodology for Conducting the Life Cycle Assessment

Objectives

The objective of the life cycle assessment was to answer two questions:

- What are the environmental and public health impacts of conversion technologies?
- How do the environmental and public health impacts of conversion technologies compare to existing MSW management practices (for example, recycling, composting, WTE combustion, landfilling)?

The study did not necessarily seek to make definitive conclusions about conversion technologies or the environmental preference of conversion technologies compared to existing MSW management options. Rather, the objective was to better understand the potential environmental and human health impacts that may result from the commercialization of conversion technologies, the tradeoffs of employing conversion technologies as alternatives to existing MSW management practices, and the variables that influence the potential environmental impacts of conversion technologies.

Approach

The term "life cycle assessment" describes a type of systems analysis that accounts for the complete set of upstream and downstream energy and environmental impacts associated with production systems. A life cycle assessment was conducted to assess the environmental performance of the hypothetical conversion technology growth scenario when compared to several alternative management scenarios involving landfill disposal, recycling, composting, and WTE. Our approach included the following steps:

1. Define the scope, boundaries, and specific process steps for the acid hydrolysis, gasification, and catalytic cracking technologies.
2. Collect data and develop materials and energy balance models for each conversion technology.
3. Construct life cycle inventory modules for each conversion technology by adding life cycle burdens and benefits to the materials and energy balance models.
4. Apply RTI's Municipal Solid Waste Decision Support Tool (MSW DST) to inventory the full life cycle impacts of the conversion technologies scenarios (from the collection of waste to its ultimate disposition), as well as for several alternative management practices involving recycling, composting, waste-to-energy, and landfill disposal.

A full life cycle assessment would also include an *impact assessment* of the potential impacts to the environment and human health. In this study, we took the life cycle assessment through an interpretation of the inventory analysis only. This is because the State of California's Office of Environmental Health Hazard Assessment will conduct a detailed risk assessment of conversion technologies upon completion of this study. Following is a brief description of each step in our approach.

Step 1. Define boundaries and process steps

Figure ES-1 illustrates the overall life cycle system boundaries for a conversion technology system. In the figure, the boundaries include not only the conversion technology and other MSW management operations, but also the processes that supply inputs to those operations, such as fuels, electricity, and materials production. Likewise, any useful energy or products produced from the conversion technology system are included in the study boundaries as offsets. An offset is the displacement of energy or materials produced from primary (virgin) resources that results from using secondary (recycled) energy or materials.

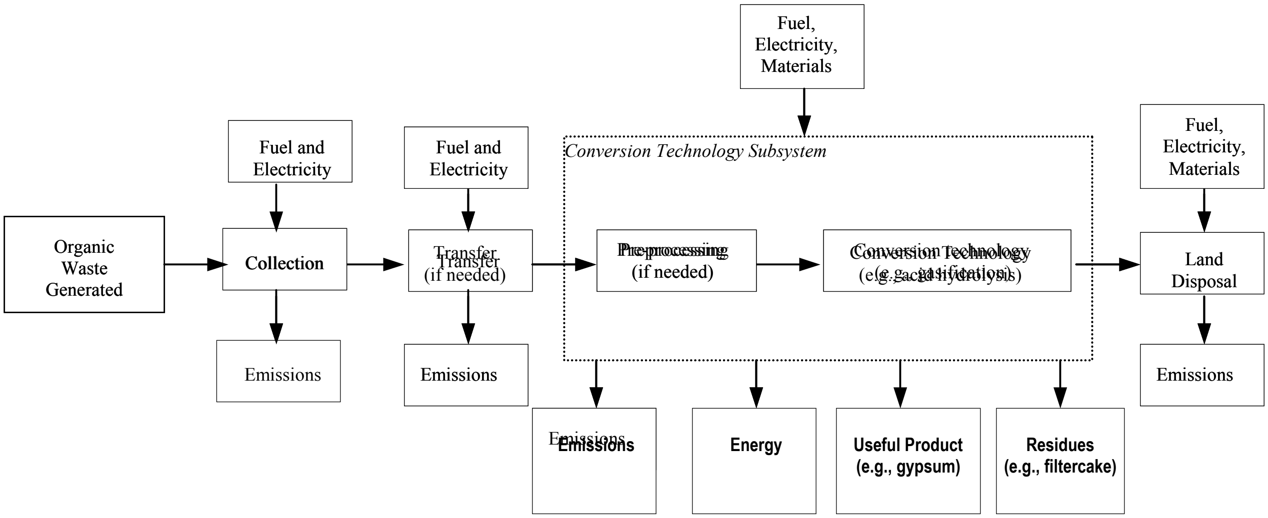


Figure ES-1. General Life Cycle Boundaries for a Conversion Technology System.

Once the specific conversion technology designs were identified based on the technical evaluation of technology vendors, detailed process descriptions and process flow diagrams were prepared to identify mass flows, energy consumption, environmental releases, and other significant waste production and resource utilization parameters. Process flow diagrams and descriptions were developed for the selected conversion technologies based on designs used by specific vendors: concentrated acid hydrolysis is based on the Masada OxyNol^{TM} technology, gasification is based on the Brightstar Environmental SWERF technology, and catalytic cracking is based on the Plastics Energy LLC/H.SMARTech technology.

Step 2. Data Collection

Through previous work conducted by RTI, extensive life cycle data have already been collected or developed for waste management processes and were available for use in this study, including energy consumption; air emissions; water effluents; solid waste for waste collection; transfer stations; materials recovery facilities (MRF); yard and mixed municipal waste composting. Other data include WTE combustion; landfill disposal; and supporting life cycle operations of electrical energy production (using national, regional, or user-defined grids), fuels production (for example, diesel fuel), virgin and recycled materials productions (for example, glass containers), and transportation (for example, over-road haul). RTI's data have been carefully documented to ensure transparency and have been thoroughly peer reviewed. Most importantly, the RTI data allowed us to focus on collecting or developing comparable data for conversion technologies.

We worked with internal and external contacts to identify available data for each of the conversion technologies. These data were used to develop emission/energy factors and cost functions for use in conducting the LCI and for the market impact assessment.

Data were collected from a variety of sources, including technology vendors, publicly available literature, federal reports, State and municipal government agencies, industry reports and, trade associations. We collected other data on waste collection, processing, and disposal facility records and reports; and from previous studies—for example, the National Renewable Energy

Laboratory biogas study. These data were used to model the conversion technologies using a commercial process engineering tool called ASPEN-Plus to obtain the material and energy balance information around each process.

Step 3. Construct Life Cycle Inventory Modules

To calculate the life cycle inventory coefficients (that is, energy consumption and environmental releases per ton of throughput) for the conversion technologies, modules were developed for the concentrated acid hydrolysis, gasification, and catalytic cracking systems. These modules rely on the material and energy balance models from the conversion step as a starting point and then add the life cycle inventory information for upstream and downstream steps. In general, the construction of modules for each conversion technology can be depicted as follows:

Materials and Energy Balance + LC input/output burdens – Offsets = Net LCI Coefficients

For example, acid hydrolysis uses sulfuric acid as a process input. The amount of acid consumed for a given tonnage of waste processed is calculated in the material and energy balance model. This amount is multiplied by the environmental burdens associated with producing the acid and added to the LCI for the technology. Similarly, the acid hydrolysis process generates some residual waste that is landfilled. The environmental burdens associated with the landfill of these residuals are added to the LCI for the technology. Material and energy offsets are netted out of the LCI. In the case of acid hydrolysis, the main product is ethanol.

Ethanol has a number of possible uses. We assumed that it would be used as a replacement to MTBE as a fuel additive; therefore, the offset associated with acid hydrolysis is the production of MTBE. The quantity of ethanol that is produced by the process (as given by the material and energy balance model) is converted to an equivalent function amount of MTBE. That amount of MTBE offset is then multiplied by the LCI burdens associated with MTBE production, and these burdens are netted out of the LCI for the technology.

Step 4. Calculate Outputs from the MSW Decision Support Tool

The main categories of life cycle inventory inputs and outputs include:

Energy consumption: Annual energy consumed is aggregated across process and transportation steps in the life cycle of each conversion technology module. Where energy is produced by a process and displaces the production of electricity or a fuel by a utility or the petroleum sector, respectively, such as the combustion of MSW with energy recovery, a credit is given to the extent that it displaces power generation by the utility sector or production of the fuel.

Air emissions: Air emissions can result from two primary sources in the life cycle: process-related activities or fuel-related activities. Process emissions are those that are emitted during a processing step, but not as a result of fuel combustion. Fuel-related emissions are those emissions that result from the combustion of fuels. Atmospheric emissions also include CO_2 releases, which are calculated from fuel combustion data or process chemistry. CO_2 emissions are not regulated; however, they are reported in this study because of the growing concern about global warming.

Waterborne pollutants: Waterborne wastes are produced from both process activities and fuel-production activities. Similar to air emissions, the waterborne pollutants include substances released to the surface and ground waters that are regulated or classified as pollutants. The values reported are the average quantity of pollutants still present in the wastewater stream after wastewater treatment and represent discharges into receiving waters.

Residual solid wastes. Similar to air and water emissions, solid wastes are produced from process and fuel production activities. Process solid wastes include mineral processing wastes (such as red mud from alumina manufacturing); wastewater treatment sludge; solids collected in air pollution control devices; trim or waste materials from manufacturing operations that are not recycled; and packaging materials from material suppliers. Fuel-related solid wastes are fuel production and combustion residues, such as the ash generated by burning coal or wood.

Life Cycle Inventory Scenarios Analyzed

Life cycle inventory results were generated for the Greater Los Angeles and San Francisco Bay Regions for the conversion technology scenario and for alternative management practices across a time period of 2003 to 2010. A total of nine scenarios were analyzed:

The **landfill scenarios** (Scenarios 1–3) assume that half of the waste is direct-hauled to the landfill and half is routed first through a transfer station. The landfill can either vent (worst case), flare (average case), or recover landfill gas for electricity production (best case).

The **WTE scenario** (Scenario 4) assumes that half of the waste is direct-hauled to the WTE plant and half is routed first through a transfer station. The WTE plant is assumed to generate electrical energy and recover ferrous metal from the combustion ash. The combustion ash is transported to an ash landfill for disposal.

The **organics composting scenario** (Scenario 5) assumes that organic materials are collected separately and taken to a compost facility. The residual (inorganic) fraction is disposed of in a landfill with gas collection and flaring.

The **recycling scenarios** (Scenarios 6–8), assume various separation efficiencies (35 percent, 55 percent, 75 percent). Separation efficiency refers to the amount of incoming recyclable material that is recovered. The unrecovered recyclable material and residual wastes are assumed to be disposed in a landfill with gas collection and flaring.

The **conversion technologies scenario** (Scenario 9) assumes that facilities for each of the three technologiesacid hydrolysis, gasification and catalytic cracking—are implemented in each region on the schedule defined for the hypothetical conversion technology scenario.

The conversion technologies and alternative scenarios were evaluated consistently on an "apples to apples" basis. We assume each of the nine scenarios manages the same quantity and composition of waste from each region for each year. For example, the same quantity and composition of MSW from the Greater Los Angeles region is sent to the conversion technology scenario, as well as to the other eight alternative scenarios. Therefore, for each region and study year, the results across the nine scenarios can be directly compared.

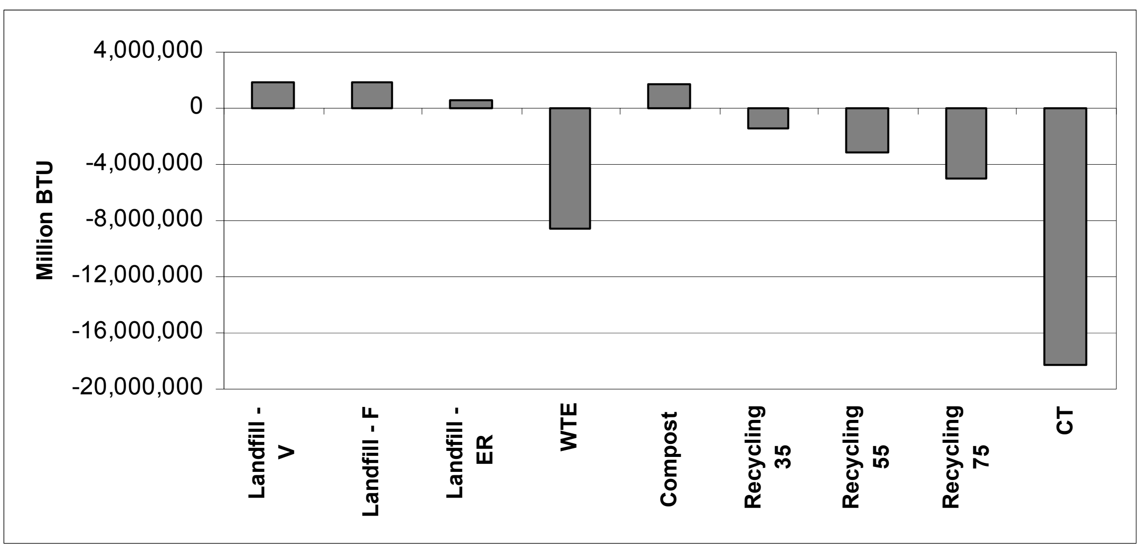
Key Findings from the Life Cycle Assessment[1]

Finding #1: The amount of energy produced by the hypothetical conversion technology scenario is larger than the alternative management scenarios studied and creates large life cycle benefits.

Energy is consumed by all waste management activities (for example, collection, MRF, transportation, treatment, disposal), as well as by the processes used to produce energy and material inputs to the conversion technologies. Energy offsets can result from the production of fuels or electricity and from the recovery and recycling of materials. Energy is an important parameter in life cycle studies, because it often drives the results of the study due to the significant amounts of air and water emissions associated with energy production.

As shown in Figure ES-2, the conversion technology scenario is much lower in net energy consumption when compared to the alternative management scenarios and is a large net energy saver[2]. The energy savings attributed to the conversion technologies result from a combination of electricity, fuel, and materials (recycling) offsets. The energy-savings potential resulting from the additional materials recycling from the gasification and acid hydrolysis preprocessing steps ranges from 10 to 20 percent of the total net energy production potential.

Figure ES-2. San Francisco Bay Region, 2010 Net Energy Consumption



[1] This section highlights key findings for four environmental impacts identified by the CIWMB as being most important: net annual energy consumption, sulfur oxide (SO_x) emissions, nitrogen nxide (NO_x) emissions, and carbon equivalents. The full report contains detailed output for more than 30 parameters for each scenario, region, and year.

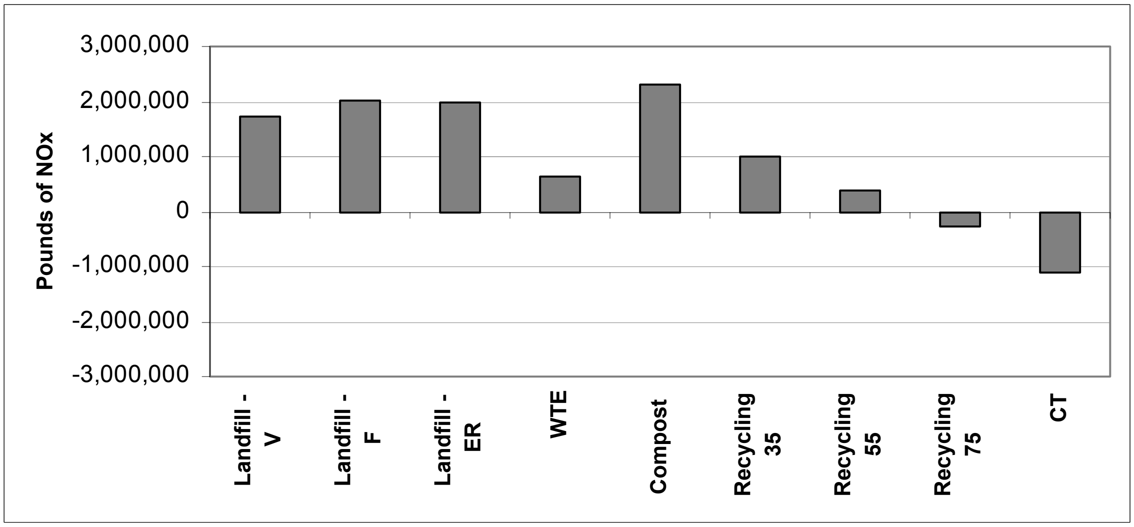
[2] For simplicity of presentation, figures accompanying life cycle assessment findings in this Executive Summary focus on the San Francisco region in the year 2010 (results for LA and other years show similar patterns).

Finding #2: For criteria air pollutants, the hypothetical conversion technology scenario is better when compared to the alternative management scenarios.

NO_x emissions can lead to such environmental impacts as smog, acid deposition, and decreased visibility. NO_x emissions are largely the result of fuel combustion processes. Likewise, NO_x emission offsets can result from the displacement of combustion activities, mainly fuels and electrical energy production.

As shown in Figure ES-3, the hypothetical conversion technology scenario showed the lowest net levels of NO_x emissions and resulted in a significant net NO_x emissions avoidance. Although the conversion technologies produce NO_x emissions, the net avoidance is a result of significant offsets associated with the production of energy and materials recycling, coupled with the low NOx emissions from the gasification plants. The only other alternative management scenario that resulted in net NO_x offset is the high (75 percent) recycling scenario.

Figure ES-3. San Francisco Bay Region, 2010 Net NO_x Emissions



SO_x emissions can lead to environmental impacts such as acid deposition, corrosion, and decreased visibility. SO_x emissions are largely a product of combustion processes. SO_x offsets can result from the displacement of combustion activities, mainly fuels and electrical energy production, as well as the use of lower-sulfur-containing fuels. As shown in Figure ES-4, the conversion technology scenario produced a large net SO_x offset that was comparable to the high (75 percent) recycling scenario. Only the WTE scenario performed better than the conversion technology scenario. A large portion of the SO_x emissions associated with the conversion technology scenario resulted not from the technologies themselves, but rather from the production of sulfuric acid used in acid hydrolysis.

Figure ES-4. San Francisco Bay Region, 2010 Net SO_x Emissions

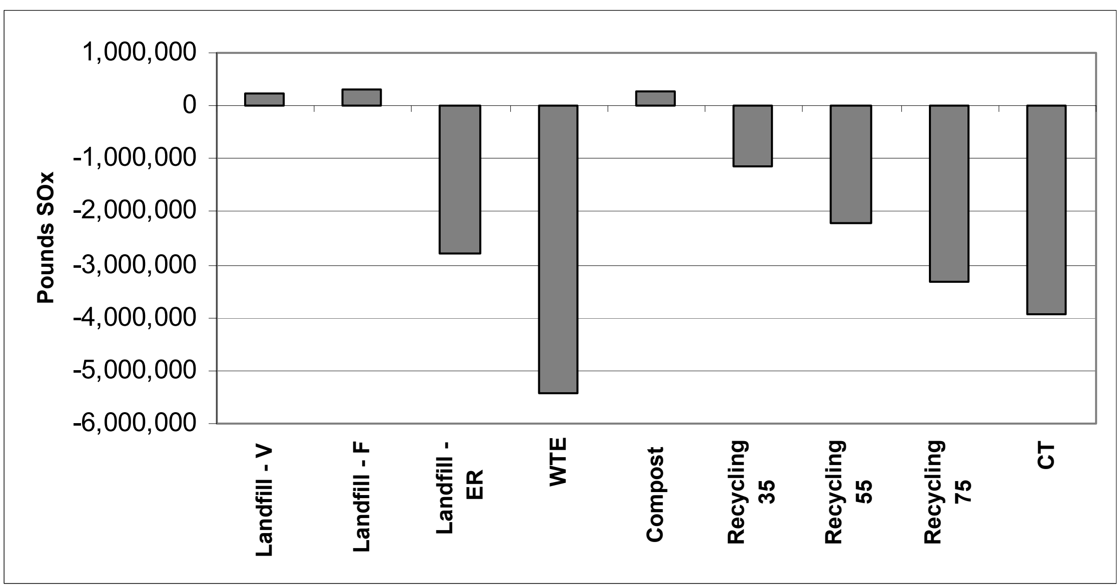
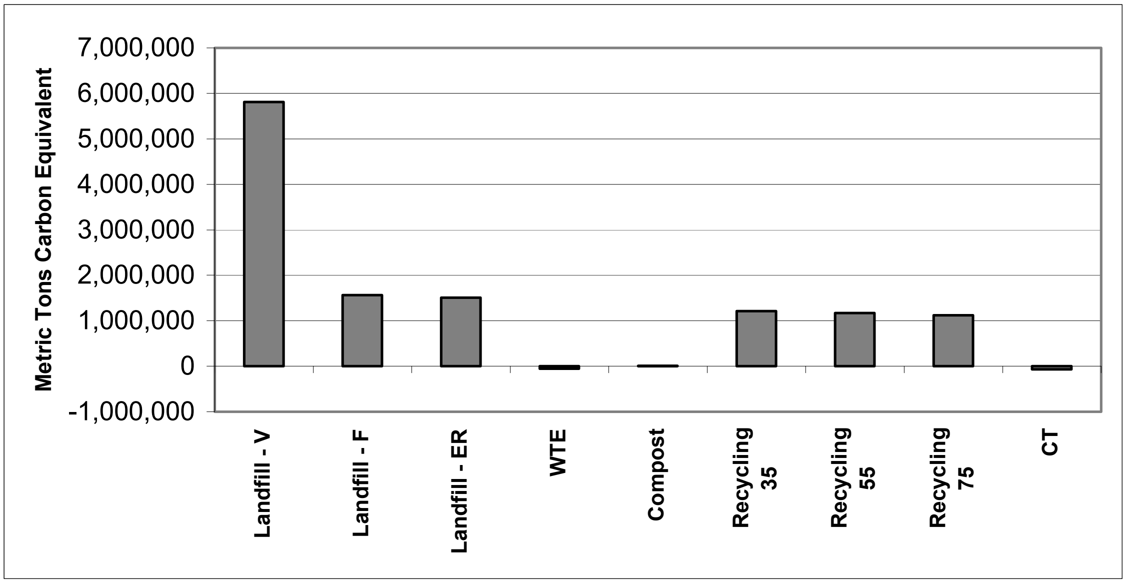


Figure ES-5. San Francisco Bay Region, 2010 Net Carbon Emissions



Finding #3: From a climate change perspective, the hypothetical conversion technology scenario is generally better than the alternative management scenarios.

Carbon emissions contribute to the greenhouse gas effect; thus, these emissions can lead to climate change and its associated impacts. Carbon emissions can result from the combustion of fossil fuels and the biodegradation of organic materials (for example, methane gas from landfills). Offsets of carbon emissions can result from the displacement of fossil fuels, materials recycling, and the diversion of organic wastes from landfills. As shown in Figure ES-5, the conversion technology scenario resulted in the lowest level of carbon emissions, comparable to the WTE and composting scenarios. The primary drivers for carbon emissions in the conversion technology scenario are the residual waste that is disposed in landfills, carbon emissions from the process steps, and carbon offsets associated with energy and materials offsets.

Finding #4: Insufficient data were available to adequately assess the potential for the hypothetical conversion technology scenario to produce emissions of dioxins, furans, and other HAPs relative to the alternative management scenarios.

In addition to the parameters discussed above, CIWMB staff also identified dioxin/furans, hazardous air pollutants (HAPs), and toxics as a priority in considering the environmental impact of the conversion technology systems. Sufficient data were not available for all of the processes in each scenario to develop comparable results.

Instead, we compared available data on dioxins, furans, and other HAPs from conversion technology processes to existing activities that involve the combustion of wastes and coal and landfill disposal. This data does not show any clear differences between HAP emission factors for the conversion technology processes, WTE, and coal utility boilers. The conversion technology processes, WTE, and coal boilers all have higher emission factors for mercury than landfilling does. If landfill fires are included, the conversion technology processes, WTE, and coal boilers all have lower emission factors for dioxins and furans than landfilling; however, if landfill fires are excluded, they have higher emission factors.

Finding #5: The environmental benefits of the hypothetical conversion technology scenario are highly dependent upon their ability to achieve high conversion efficiencies and materials recycling rates.

In terms of life cycle energy consumption, employing the conversion technologies may result in a net energy savings when compared to landfill disposal options because the conversion technologies produce energy (electrical energy and fuels), which offsets energy production from fossil sources. The magnitude of the energy-related offsets is significant and provides one of the main benefits of employing conversion technologies. In addition to energy production, acid hydrolysis and gasification technologies can lead to further materials recycling. The additional recycling benefit can also be quite significant. Therefore, the more efficiently the conversion technologies transform waste into energy (or other products) and the more effectively they recover additional materials for recycling, the greater the life cycle environmental benefits.

Finding #6: Conversion technologies would decrease the amount of waste disposed of in landfills.

We assumed that about half of the incoming material that is removed from the conversion technology processes is recycled and the other half landfilled (except for metals, for which we assumed about 70 percent recycled and 25 percent landfilled). Because of the burdens associated with landfill disposal, the conversion technology scenario would look worse if zero recycling were assumed and much better if high rates of recycling were assumed. In addition, the life cycle assessment does not capture issues about landfill space and the potential benefits of conversion technologies in reducing the amount of needed landfill space as a result of materials recovery. There is also some process waste generated from the conversion technologies that needs to be landfilled. For example, gasification produces char that is disposed of in a landfill.

Finding #7: No conversion technology facilities exist in the United States for MSW; therefore, there is a high level of uncertainty regarding their environmental performance.

The amount of unwanted metals, glass, and plastics that the conversion technology facilities will be able to remove through the up-front separation and preprocessing steps is unknown. For this study, we assumed a 5 percent contaminant level entering the conversion technology process. Higher levels of process contaminants would result in higher levels of local pollutants.

Key Assumptions and Related Uncertainties of Life Cycle Assessment Results

Highlighted below are some of the key variables and uncertainties involved in conducting this life cycle assessment. As noted, in many cases adjusting these variables would not substantially affect the study's conclusions.

Co-location with MRFs—We assumed that the conversion technology facilities would be co-located with existing or new MRF operations that accept mixed waste; however, the conversion technologies could also be located independent of MRFs. Whether the MRF and conversion technologies are co-located or not will not significantly affect the life cycle inventory results, since the additional transportation involved will not be significant in terms of the inventory totals.

***Optimal Siting*—**We considered the hypothetical conversion technology scenario and alternative scenarios separately, without attempting to identify optimal combinations of conversion technologies. Such an optimization process was beyond the scope of this study.

***One hypothetical development scenario*—**We assumed one particular conversion technology development scenario. The results of the life cycle inventory are largely linear; therefore, the relative size of the results between scenarios would be the same regardless of the facility size. Locations with significantly different waste compositions from Greater Los Angeles or San Francisco Bay would produce different results; however, the directional results between the alternative scenarios (that is, landfill, WTE, recycling, compost, and conversion technology) would likely be similar.

***Recyclables marketed domestically*—**We assumed that recyclables are marketed domestically. Although the use of domestic versus international markets for recyclables might be significant in a study of optimal recycling strategies, in this study, the transportation step for hauling recyclables from the MRF to a remanufacturing facility is not significant when compared to the life cycle inventory totals.

***Mixed waste rather than source-separated feedstock*—**For the majority of conversion technology tonnage (acid hydrolysis and gasification), we assumed that the material entering the conversion technology facilities is mixed MSW, rather than source-separated waste streams. For catalytic cracking, we assumed that 50 percent of the feedstock is mixed MSW and 50 percent is source-separated plastic.

The implication of this assumption for acid hydrolysis and gasification is that the conversion technologies must preprocess the waste prior to use in the conversion process. This preprocessing step produces feedstock that is amenable to each technology and recovers a significant amount of recyclable materials (for example, metals) that are not amenable to use in the technologies. Non-usable and unrecovered recyclables are assumed to be disposed in a landfill.

***MSW as feedstock*—**We assumed the feedstock for the conversion technology scenario came from the MSW stream. We did not analyze the use of non-municipal wastes, such as agricultural waste, construction and demolition waste, and sewage sludge. The implications of analyzing MSW as feedstock largely resides in the additional recycling achieved by the conversion technology scenario processing MSW. For example, if agricultural, C&D, or sewage sludge are used, there may be little or no additional materials recovery. The recycling benefits in the conversion technology scenario are approximately 10 to 20 percent of the totals.

***Source-separated organics as feedstock*—**For the compost scenario, we assumed a source-separated organics-only facility, because these are the only types of compost facilities in California. We assumed that the organic material is source-separated, and the remaining, inorganic fraction is landfilled. If a mixed MSW compost facility were modeled, the results would differ by the amount of difference between the landfill and compost options.

National average statistics—In many cases we used national average statistics instead of California-specific averages. For the hypothetical conversion technology scenario, we assumed the facilities would be similar to the existing or described technologies devised by the vendors, relying on information they provided and the public literature. For the alternative MSW management scenarios, the facility designs and operating parameters are based largely on the national average default values contained in the MSW DST of RTI. Although actual design and operating parameters for facilities in California may differ from the national averages, we would expect the same directional results as obtained in this study.

Methodology for Conducting the Market Impact Assessment

Objectives

The purpose of the market impact assessment was to determine the economic, financial, and institutional impacts of conversion technologies on recycling and composting markets. The following specific objectives guided the assessment:

<u>Economic and Financial Objectives</u>

- Estimate the impacts on recycling and composting industries due to potential increases or decreases in feedstock supply (in tons) from new conversion technology facilities. If there is a tonnage impact, estimate the revenue gain or loss and the impact on employment levels. If there is a price impact, determine the impact on total revenue.
- Estimate which technology configurations have the greatest and least impact on recycling and composting.

<u>Institutional Impacts</u>

- Estimate impacts on hauler contractual relationships.
- Estimate impacts on municipal contractual relationships.
- Estimate the impacts on regional recycling and composting infrastructure and siting of new facilities.
- Estimate the impacts of conversion technology put-or-pay contracts on recycling and composting businesses.

Methodology

The methodology for conducting the market impact assessment involved determining baseline projections for waste management practices and recycling in each study region, adjusting these baseline projections by overlaying the hypothetical conversion technology scenario described earlier, and then analyzing the likely impacts.

Additionally, CIWMB also asked the study team to evaluate how these findings would change if the State adopted certain adjustments to State policy on allowing diversion credit for waste sent to conversion technology facilities. The study findings are based on the assumption that private sector decision-makers act to maximize profit, and that public sector decision makers act to minimize cost with the additional responsibility of achieving Integrated Waste Management Act (IWMA) diversion mandates and operating sound solid waste management systems.

The project team identified, reviewed, and compiled a vast amount of data and information related to conversion technology facilities and California waste management practices and markets. Primary data sources included interviews with conversion technology developers, government solid waste and recycling officials, industry experts, and review of conversion technology bid and contractual documents.

Secondary data sources included the CIWMB and other State and federal agencies, industry trade associations, industry publications, previously prepared reports and Hilton, Farnkopf, & Hobson's in-house data and information. The data gathering effort was supplemented by a concurrent

CIWMB-sponsored University of California survey of conversion technologies, and by information and modeling conducted by the National Renewable Energy Laboratory.

The main data analysis steps included:

- Characterizing the market place for potential conversion technology feedstock types, including mixed municipal solid waste; residuals from materials recovery facilities; and recyclable paper, plastics, green waste, and other organic materials. This included analysis of the quantity projected to be available, export trends, demand trends, pricing trends, and the key factors influencing future trends. Recycling growth projections were based on municipally planned programs, average growth rates for each material, and consideration of factors affecting markets.
- Characterizing the composition of mixed waste and MRF residuals available to conversion technology facilities. This required developing baseline waste composition estimates based on statewide averages, and then adjusting them to reflect the population of each study region, recycling growth, and population increases.
- Estimating the specific feedstock needs of each type of conversion technology and developing assumptions for the types of sorting and other preparation required. This included estimating the amount of additional recycling likely to occur as a result of feedstock treatment at CT facilities.
- Characterizing the types of existing institutional arrangements, including contractual terms currently used by municipalities related to their solid waste and recycling objectives. This also included an analysis of California jurisdictions interested in conversion technology.
- Analyzing likely conversion technology pricing and contractual arrangements.
- Analyzing typical materials recovery facility and recycling collection economics.
- Analyzing typical jobs and revenue associated with recycling and conversion technology activities.

A financial spreadsheet model was developed to facilitate compiling and analyzing these data, to allow comparison of different scenarios, and to estimate total employment and revenue impacts.

Key Findings from the Market Impact Assessment

Impacts on Recycling and Composting Markets

Finding #1: There is a projected net positive impact on glass, metal, and plastic recycling under the hypothetical conversion technology scenario assumed in this study.

This hypothetical scenario assumes mixed waste is the primary feedstock for conversion technology facilities (whether MRF residuals or from garbage collection routes). This is due to favorable economics relative to other separated feedstock sources. The scenario assumes no changes in current recycling economics (that is, prices remain approximately the same and demand remains strong), and no changes in state law to allow diversion credit for conversion technologies.

Using mixed solid waste as feedstock, preprocessing results in removal of 7 to 8 percent of feedstock for recycling at gasification facilities and 12 to 13 percent of feedstock for recycling at acid hydrolysis facilities. The new recycling is related to conversion technology preprocessing operations. Certain materials, such as glass and metals, can reduce the efficiency of conversion technology operations and can improve the economics of the system if they are recovered and sold.

In addition, plastics recycling will increase if acid hydrolysis facilities are built because plastics must be removed prior to processing. Currently, only those plastics with positive economic values are typically recycled. In contrast, feedstock preparation for acid hydrolysis would seek to remove all plastics. Because organics will not be removed through sorting, the scenario results in no increases or decreases to compost markets.

The increased recycling yields job creation in sorting and end-use industries. (See finding #14.) The quantities recovered, however, would not be large enough to have a price impact on local recycling industries.

Finding #2: Implementation of any of the three conversion technologies is not likely to increase or decrease the recycling of paper.

Although paper is an acceptable feedstock for acid hydrolysis and gasification, the value of baled paper makes it unlikely that paper separated for recycling will be directed to a conversion technology facility. Paper markets are historically very volatile, with high prices in a given year being twice that of low prices for that year.

However, average annual paper prices have been above zero for a 10-year period for all paper grades and have risen to more than $100 per ton for some grades of paper. Acid hydrolysis and gasification projects will require a payment (a tipping fee) to accept materials, and that tipping fee will likely be in the range of prices charged at local landfills ($25 to $60 per ton).

Finding #3: Conversion technology facilities accepting separated materials with no recycling or composting markets will have no impact on current recycling and composting markets.

For example, if catalytic cracking were to target mixed plastics, grades 4 through 7, it would likely have an insignificant impact on current recycling markets and no impact on composting markets. Many materials currently have no viable markets, but they could provide feedstock for various conversion technology processes. The likelihood of this happening will depend on economics and local conditions. The sum of costs (for feedstock preparation, sorting, transportation, and conversion technology tipping fees) would have to be lower than the current alternatives in order to be a viable option.

Finding #4: The impact of increasing exports, especially to China, is a far more dominant force on paper and plastics markets than potential development of conversion technologies in California, even on the fairly large scale that was assumed for this study.

Exports of paper and plastics, particularly to China, have increased dramatically over the past five years. These exports are exerting upward pressure on prices in the paper and plastics markets and are providing an outlet for all of the paper and plastics that are collected. Paper exported from this country has grown significantly in recent years: by 77 percent from 1993 to 2002, or an average of 6.5 percent per year. Nationwide, 24 percent of the paper recovered in the United States is exported for recycling.

Locally, exports from the Greater Los Angeles region increased 12.1 percent per year on average from 1998 to 2002, and exports from the San Francisco Bay region increased an average of 13.8 percent per year from 1998 to 2002. China has been the dominant driver of these increases in paper exports. During the five-year period from 1998 to 2002, exports to China from these two California port areas have increased by 209 percent and represent 48 percent of the total exports for this period.

The growth figures cited above are for the sum of the most common grades of recycled paper. Different paper grades have grown at different levels. In particular, most of the recent growth has been in the area of mixed paper. Mixed paper previously had a value that was too low for economic recovery, but now it is priced high enough to make its recovery profitable.

Although available plastics statistics are not as detailed as those for paper, recent news articles and discussions with plastics recyclers indicate that Chinese demand for recycled plastics has led to upward price pressure, in some cases leading to a doubling of prices. In the case of PET only, the increased demand for material is accompanied by stagnant levels of PET collection nationwide, which has caused material shortages for U.S. PET recyclers. Statistics from the National Association for PET Container Resources (NAPCOR) indicate that exports of PET increased 50 percent from 1999 to 2002 and now absorb 34 percent of PET collected nationally.

Finding #5: Though unlikely, future recycling growth could be negatively impacted by conversion technology facilities in three ways.

Future recycling growth could be negatively impacted in the following ways if recyclables were redirected to conversion technology facilities:

a) Source-separated recyclables or green waste could flow to conversion technology facilities rather than recycling facilities.

b) If markets for currently untapped waste streams significantly improved (for example, low quality mixed waste paper), the materials may be unavailable to recyclers because they are already committed to conversion technology facilities.

c) If municipalities eliminated or reduced recycling and green waste collection programs and instead redirected mixed waste to conversion technology facilities.

These three possible—but unlikely—negative impacts are discussed below in the next three findings.

Finding #6: Source-separated recyclables (paper and plastics) are not likely to flow to conversion technology facilities, based on pricing differentials.

Source-separated paper and plastics currently are recycled for profit. Even if market prices declined dramatically, conversion technology would still likely be more expensive than recycling. Furthermore, collection of source-separated recyclables would cease because collection would no longer be economical (revenues from sales of materials would not cover collection costs).

Exceptions to this finding would include conditions of extremely low recycling price swings, extremely low conversion technology tip fees (for example, caused by changes in technology or contracts), or the temporary collapse of export markets. All of these conditions are possible, but not foreseeable. If catalytic cracking facilities target plastic bags, then some jurisdictions might add plastic bags to their curbside recycling programs. Residents might stop returning plastic bags to grocery stores for recycling, resulting in a very small impact on existing recycling markets.

Finding #7: Conversion technology facilities might negatively impact the ability of municipalities and private companies to increase recycling from currently untapped waste streams and generators, but the net effect of this is projected to be minimal.

The minimal impact is projected because many municipalities are already planning recycling growth in order to comply with IWMA mandates, and that growth is already accounted for in the waste composition projections used in this study. Furthermore, the cost of tapping these waste streams is high, and private recyclers only have access to a small portion of the waste stream because municipalities control most of the waste stream, either directly or through exclusive contracts with waste haulers.

Extreme conditions that might change this finding include changes in the recycling markets (for example, far higher prices and demand) or recycling technology (for example, automated sorting technologies), new commitments to recycle by waste generators as a result of legislation or product stewardship commitments, or through municipalities that might be attracted to conversion technology as part of municipal plans to maximize recycling and focus on "zero waste" strategies.

Finding #8: Source-separated green waste from MSW could conceivably flow to conversion technology facilities under certain circumstances. However, assuming no diversion credit is allowed for conversion technologies, this is very unlikely.

Significant quantities of green waste currently delivered to composters or to landfills (as alternative daily cover) will most likely not be redirected to conversion technology facilities for the following reasons:

First, jurisdictions that contract for source-separated green waste collection will continue to require their contractors to deliver it to facilities that qualify for diversion credit (about 80 percent of this material currently flows to green waste diversion facilities).

Second, about 20 percent of the green waste delivered to diversion facilities pay posted rates, currently about $11 to $31 per ton in the Greater Los Angeles region and $15 to $40 in the San Francisco Bay region. Conversion technology prices will probably not be competitive for most of this tonnage.

Third, conversion technology facilities will be most interested in steady waste flows from contract haulers rather than the uneven flow delivered in loads from self-haulers. If green waste is sent to conversion technology facilities based only on price, composting and mulching facilities are likely to be impacted more than facilities using green waste as alternative daily cover (ADC). This is because ADC prices are generally much lower. Finally, sufficient refuse tonnage is available to fully utilize the capacity of the assumed hypothetical conversion technology scenario that is more economic than separated green waste.

The above assessment is contingent on a policy of not providing diversion credit for conversion technology facilities. If diversion credits were provided without regulatory measures to protect current recycling, public agencies would have an economic incentive to discontinue separate green waste collection. Instead they would deliver mixed loads of refuse and green waste to conversion technology facilities, because these facilities would likely be less costly as a result of savings in waste hauling costs. (See finding #15 below.)

Alternatively, if green waste markets collapse, perhaps as a result of increased air quality regulations or decreased ADC use, then conversion technology may be an attractive outlet for these materials. Furthermore, for agricultural and wood wastes that are outside of the scope of this study, conversion technology might compete with biomass markets.

Impacts on Landfill Markets

Finding #9: The amount of waste used in the hypothetical conversion technology scenario would have a larger impact on the San Francisco landfill market than on the Los Angeles landfill market.

In the hypothetical scenario, conversion technology facilities would consume approximately 1.4 million tons of waste in each of the two regions in 2003, rising to 2.2 million tons in 2010. This represents about 7 percent of the landfill tonnage in the Greater Los Angeles region in 2003, increasing to 11 percent in 2010. The same facilities would have a greater impact on the San Francisco landfill market, with conversion technology tonnage representing about 22 percent of the landfill tonnage in 2003 and rising to 33 percent in 2010.

Impacts on Existing Institutional Arrangements

Finding #10: Although conversion technology facilities may add innovative new options to existing integrated waste management schemes, they won't likely result in fundamental changes to existing institutional arrangements.

Ultimately, jurisdictions control most of their waste streams and have the right to contract with others to handle the wastes generated within their boundaries. Most waste is collected and transported to landfills or diversion facilities by waste haulers, jurisdictional agencies, or self-haulers.

If developed, conversion technology facilities may exist as stand-alone facilities, but more likely they will arrange to receive materials through contracts with jurisdictions, haulers, or both. In this way, conversion technology facilities will not change existing institutional arrangements. Rather, if they are developed, they will fit within the structure that already exists, augmenting the options that are currently available. Indeed, many conversion technology developers are seeking to obtain contracts with jurisdictions and waste haulers.

Finding #11: Assuming conversion technology is not eligible for diversion credit, most municipalities are not likely to shift from existing recycling programs to conversion technology contracts.

Most municipalities are slow to change their practices because integrated waste management systems are planned throughout a 5- to 10-year planning horizon, at a minimum. However, in some circumstances, municipalities will seek to contract with or own a conversion technology facility, perhaps as an alternative to a landfill.

Finding #12: Because conversion technology facilities require large capital investments (ranging from $40 million to $70 million), the facilities will likely require contractual commitments from municipalities or haulers to secure the waste streams that will supply the facilities.

The facilities and their investors or lenders may require this guaranteed revenue stream before undertaking the financial risk. Smaller, modular facilities will experience similar debt service commitments when evaluated on a per ton basis.

Finding #13: A small but significant number of municipalities are interested in exploring conversion technology as an alternative to landfill.

These municipalities appear to be attracted to the possibilities that conversion technologies offer, including creation of an alternate renewable energy source, reduction of waste to landfills (with or without diversion credit), and a more local facility alternative than distant regional landfills. For some, conversion technology facilities will offer financial benefits in areas where landfills are distant and/or have high tipping fees. Another potential benefit is increased diversion from feedstock preprocessing, which can aid jurisdictions in meeting their IWMA goals.

Economic Impacts

Finding #14: The hypothetical conversion technology growth scenario assumed in this study will generate additional recycling-related jobs for MRF sorters and in the recovered-materials industry.

The tonnage and employment impacts associated with each of the three conversion technologies included in the study's hypothetical growth scenario are summarized in Table ES-3 below. Employment gains results from additional materials recovery facility sorting positions, additional employment at end-use recycling facilities, and at the conversion technology facilities themselves. Some losses in employment may eventually result at landfills.

Table ES-3. Additional Material Diverted and Jobs Potentially Created Through Sorting of Feedstock for Conversion Technology Facilities

Material	Jobs per 1,000 Tons[a]	Tons—2003[b]	Additional Jobs—2003	Tons—2010[b]	Additional Jobs—2010
Greater Los Angeles Region—Acid Hydrolysis					
Plastic	77.1	36,109	2,784	61,353	4,730
Glass	5.0	17,960	90	28,946	145
Metal	8.3	35,778	297	57,656	479
MRF	0.72	89,847	65	147,955	107
Total			3,236		5,461
San Francisco Bay Region—Acid Hydrolysis					
Plastic	77.1	34,784	2,682	59,419	4,581
Glass	5.0	18,628	93	31,050	155
Metal	8.3	46,208	384	77,223	641
MRF	0.72	99,620	72	167,692	121
Total			3,231		5,498
Greater Los Angeles Region—Gasification					
Glass	5.0	21,024	105	30,423	152
Metal	8.3	41,882	348	60,599	503
MRF	0.72	62,906	45	91,022	66
Total			498		721
San Francisco Bay Region—Gasification					
Glass	5.0	21,904	110	32,763	164
Metal	8.3	54,334	451	81,483	676
MRF	0.72	76,238	55	114,246	82
Total			616		922
Greater Los Angeles Region—Catalytic Cracking					
MRF—Sorting of film plastics	0.72	16,450	12	16,450	12
San Francisco Bay Region—Catalytic Cracking					
MRF—Sorting of film plastics	0.72	16,450	12	16,450	12

[a] Calculated using jobs per ton factors in the *U.S. Recycling Economic Information Study* by R. W. Beck, Inc., July 2001. This table does not include landfill or conversion technology facility jobs.
[b] Assumes conversion technology facilities are operating at full capacity under proposed configurations.

Impacts of Changes in Conversion Technology Diversion Credit Policy

Finding #15: The impact of conversion technologies on recycling and composting markets is significantly influenced by State policy on whether to allow diversion credit.

Findings #1 through #14 assume that municipalities do not receive diversion credit for waste materials sent to conversion technology facilities. The Board also asked the study team to examine how different diversion credit policies might impact the results. Four additional diversion credit scenarios were developed based on a CIWMB policy on diversion credit for conversion technologies adopted in April 2002. (The policy was eventually superceded by the passage of AB 2770, denying diversion credit for conversion technologies and calling for this study.)

The financial spreadsheet model used to derive the above findings was again applied to each of these scenarios. The results are presented in Table ES-4 for the Greater Los Angeles region and Table ES-5 for the San Francisco Bay region. The following sections briefly define each scenario and summarize the modeling results.

<u>Scenario 1 assumes no diversion credit is given for conversion technology and has a positive impact on recycling and composting</u>. This is the scenario discussed in findings #1 through #14 above.

<u>Scenarios 2Aand 2B allow diversion credit only for material currently destined for landfill that is redirected to conversion technology facilities (with overall diversion capped at 10% under scenario 2B). Both scenarios have a positive impact on recycling and composting.</u> Under both scenarios, jurisdictions would make no changes to their diversion programs. Sufficient tonnage to meet the needs of the assumed hypothetical conversion technology scenario would be available, provided the Greater Los Angeles region's conversion technology tipping fee did not greatly exceed $40 per ton and the San Francisco Bay region's conversion technology tipping fee did not greatly exceed $50 per ton.

Under Scenario 2A, in the Greater Los Angeles region, the demand for conversion technology facilities would exceed available conversion technology facility capacity. However, under Scenario 2B, the demand would only be for around 72 percent of the available capacity. In the San Francisco Bay region, the tonnage demand was estimated at 62.5 percent and 40 percent of available capacity for Scenario 2A and Scenario 2B, respectively.

Both scenarios would provide increased recycling market revenue, jobs, and tonnage. Increased revenue could be as high as $171 million to $400 million per region per year over the study term. Additional jobs could be from 1,500 to 3,600 per region over the study term. Additional recycling tonnage would be 70,000 to 153,000 per region per year over the study term. Landfill revenue, tonnage, and jobs would decrease under both scenario 2A and 2B.

<u>Scenario 3 assumes conversion technology is given full diversion credit, and that municipalities discontinue collection of both separated recyclables and green waste. This would have a mostly negative impact on recycling and composting.</u> This scenario assumes all residential material (refuse, recyclables, and green waste) is sent to conversion technology facilities. Jurisdictions could realize significant collection cost savings by collecting all materials with a single truck.

This scenario assumes the gasification and acid hydrolysis facilities operate at full capacity. Over 500,000 fewer tons in each region may be available to the recyclables and organics markets. The materials recovered would be plastic, metal, and glass. Paper and organics, which comprise the majority of the recyclable materials present in the feedstock, would not be recovered.

Far fewer tons of recyclables will be recovered through presorting than would be recovered if the recyclables and organics were separated and sent to other processing facilities. But the effect on recyclables revenue and recyclables job creation may still be positive. According to ratios based on data from the *U.S. Recycling Economic Information Study*, organics and paper generate far fewer jobs and less revenue per ton than plastics.

A combination of the recyclables recovered from the refuse is sent to conversion technology. Of the plastic that is recovered in the gasification process, the revenue and job effect on the recyclables industry is slightly positive. However, if the plastics industry ratios were similar to levels found for other recyclables, the effect on the recyclables industry would be negative in all categories.

The net effect on organics markets would be a decrease of approximately 76 jobs in each region and $7 million to $10 million in annual revenue for the organics industry per region over the study term. Approximately 364,000 of the more than 500,000 net recoverable tons lost to the conversion technology process would be organics.

<u>Scenario 4 assumes conversion technology is given full diversion credit, and that municipalities discontinue green waste collection but continue recycling collection. This has a net positive impact on recycling.</u> Under this scenario, cities keep their source-separated recyclables programs, but they discontinue their source-separated organics collection and instead have organics and refuse collected in the same stream. Jurisdictions could realize significant collection cost savings by collecting refuse and green waste materials with a single truck. This mixed waste stream would be sent to conversion technology facilities. This scenario assumes the gasification and acid hydrolysis facilities operate at full capacity.

For example, in 2003 under Scenario 4, in the Greater Los Angeles region, 399,994 fewer tons of organics may be available for use as compost, mulch, and ADC. However, more than 102,344 additional tons of recyclable materials may be recovered from this mixed feedstock. Thus, the net loss of recoverable tons may be almost 300,000 tons per year.

According to ratios based on data from the *U.S. Recycling Economic Information Study*, additional jobs created by the recyclables removed from the feedstock during the presort for the conversion technology facility would dwarf the number lost in the organics industry. This number would equal 2,400 to 4,200 recycling jobs over the study term, versus losing 84 organics jobs. However, this is partially due to a high number of jobs per ton calculated for the plastics industry.

The jobs created are due to sorting the refuse portion of the materials sent to conversion technology facilities, not the organics portion. Sending organics to conversion technology facilities does not generate jobs for the recycling industry. Over the study term, revenue loss to the organics industry could be $8 million to $11 million per region per year. The revenue increase to the recycling industry could be significantly higher, $292 to $620 million per year over the study term, depending upon the region.

Table ES-4. Effect of Changing Diversion Credit Policies - Greater Los Angeles Region

Total Tons To CT Facilities, 2003 - Greater Los Angeles Area

	Scenario 1	Senario 2A	Senario 2B	Scenario 3	Scenario 4
Diverted from Landfills	1,367,857	1,367,857	1,176,356	683,928	916,464
Diverted From Recycling Facilities	-	-	-	262,783	-
Diverted From Green Waste Facilities	-	-	-	363,631	399,994
Total To CT Facilities	1,367,857	1,367,857	1,176,356	1,310,342	1,316,458
Recyclables Removed	152,753	152,753	131,368	108,861	102,344
Contaminants Removed	76,282	76,282	65,602	57,966	71,109
Processed Through CT (1)	1,138,822	1,138,822	979,386	1,143,515	1,143,005

Impact on Recycling and Organics Markets, 2003 - Greater Los Angeles Area

	Scenario 1	Senario 2A	Senario 2B	Scenario 3	Scenario 4
	CTs at maximum capacity using LF tons as feedstock	D.C. for Refuse to CT to Meet 50% Diversion Goal	D.C. for Refuse to CT to Meet 50% Diversion with 10% cap	D.C. for all solid waste all res to CT	D.C. for all solid waste Res Refuse and Green Waste CT
Recycling Markets					
Revenue Increase (Decrease)	$ 436,167,031	$ 436,167,031	$ 375,106,586	$ 30,983,764	$ 292,231,435
Jobs Increase (Decrease)	3,630	3,630	3,121	491	$ 2,432
Tons Increase (Decrease)	152,753	152,753	131,368	(153,922)	$ 102,344
Organics Markets					
Revenue Increase (Decrease)	$ -	$ -	$ -	$ (7,232,621)	$ (7,955,881)
Jobs Increase (Decrease)	-	-	-	(76)	$ (84)
Tons Increase (Decrease)	-	-	-	(363,631)	$ (399,994)

Total Tons To CT Facilities, 2010 - Greater Los Angeles Area

	Scenario 1	Senario 2A	Senario 2B	Scenario 3	Scenario 4
Diverted from Landfills	2,151,060	2,151,060	1,548,764	1,075,530	1,441,210
Diverted From Recycling Facilities	-	-	-	414,260	-
Diverted From Green Waste Facilities	-	-	-	571,421	628,564
Total To CT Facilities	2,151,060	2,151,060	1,546,764	2,061,211	2,069,774
Recyclables Removed	238,977	238,977	172,063	171,849	160,114
Contaminants Removed	122,541	122,541	88,228	92,429	113,530
Processed Through CT (1)	1,789,542	1,789,542	1,288,473	1,796,673	1,796,130

Impact on Recycling and Organics Markets, 2010 - Greater Los Angeles Area

	Scenario 1	Senario 2A	Senario 2B	Scenario 3	Scenario 4
	CTs at maximum capacity using LF tons as feedstock	D.C. for Refuse to CT to Meet 50% Diversion Goal	D.C. for Refuse to CT to Meet 50% Diversion with 10% cap	D.C. for all solid waste all res to CT	D.C. for all solid waste Res Refuse and Green Waste CT
Recycling Markets					
Revenue Increase (Decrease)	$ 873,691,646	$ 873,691,646	$ 751,367,273	$ 101,481,223	$ 585,366,635
Jobs Increase (Decrease)	6,018	6,018	5,176	1,011	$ 4,032
Tons Increase (Decrease)	238,977	238,977	205,520	(242,411)	$ (160,114)
Organics Markets					
Revenue Increase (Decrease)	$ -	$ -	$ -	$ (14,456,951)	$ (15,902,669)
Jobs Increase (Decrease)	-	-	-	(120)	$ (132)
Tons Increase (Decrease)	-	-	-	(571,421)	$ (628,564)

D.C. = Diversion Credit

(1) Processed through CT, net of residuals left after processing.

Table ES-5. Effect of Changing Diversion Credit Policies—San Francisco Bay Region

	Scenario 1	Scenario 2A	Scenario 2B	Scenario 3	Scenario 4
Diverted from Landfills	1,396,423	872,765	558,569	698,212	935,604
Diverted From Recycling Facilities	-	-	-	262,783	-
Diverted From Green Waste Facilities	-	-	-	363,631	399,994
Total To CT Facilities	1,396,423	872,765	558,569	1,324,626	1,335,598
Recyclables Removed	175,858	109,911	70,343	120,413	117,825
Contaminants Removed	83,155	51,973	33,262	61,402	75,715
Processed Through CT (1)	1,137,410	710,881	454,964	1,142,811	1,142,058
Impact on Recycling and Organics Markets, 2003 - San Francisco Bay Area					
	Scenario 1	Scenario 2A	Scenario 2B	Scenario 3	Scenario 4
	CTs at maximum capacity using LF tons as feedstock	D.C. for Refuse to CT to Meet 50% Diversion Goal	D.C. for Refuse to CT to Meet 50% Diversion with 10% cap	D.C. for all solid waste all res to CT	D.C. for all solid waste Res Refuse and Green Waste CT
Recycling Markets					
Revenue Increase (Decrease)	$428,660,336	$267,912,636	$171,468,406	$ 27,214,344	$287,210,262
Jobs Increase (Decrease)	3,705	2,315	1,482	528	$ 2,482
Tons Increase (Decrease)	175,858	109,911	70,343	(142,370)	$ (117,825)
Organics Markets					
Revenue Increase (Decrease)	$ -	$ -	$ -	$ (10,145,305)	$ (11,159,833)
Jobs Increase (Decrease)	-	-	-	(76)	$ (84)
Tons Increase (Decrease)	-	-	-	(363,631)	$ (399,994)
Total Tons To CT Facilities, 2010 - San Francisco Bay Area					
	Scenario 1	Scenario 2A	Scenario 2B	Scenario 3	Scenario 4
Diverted from Landfills	2,204,254	1,377,659	881,702	1,102,127	1,476,850
Diverted From Recycling Facilities	-	-	-	414,260	-
Diverted From Green Waste Facilities	-	-	-	571,421	628,564
Total To CT Facilities	2,204,254	1,377,659	881,702	2,087,808	2,105,414
Recyclables Removed	281,938	176,211	112,775	193,331	188,899
Contaminants Removed	135,730	84,833	54,293	99,023	122,367
Processed Through CT (1)	1,786,586	1,116,615	714,634	1,795,454	1,794,148
Impact on Recycling and Organics Markets, 2010 - San Francisco Bay Area					
	Scenario 1	Scenario 2A	Scenario 2B	Scenario 3	Scenario 4
Recycling Markets					
Revenue Increase (Decrease)	$924,672,794	$577,922,123	$369,874,552	$103,369,063	$619,534,694
Jobs Increase (Decrease)	6,194	3,872	2,478	1,099	$ 4,150
Tons Increase (Decrease)	281,938	176,211	112,775	(220,929)	$ 188,899
Organics Markets					
Revenue Increase (Decrease)	$ -	$ -	$ -	$ (20,285,446)	$ (22,314,022)
Jobs Increase (Decrease)	-	-	-	(120)	$ (132)
Tons Increase (Decrease)	-	-	-	(571,421)	$ (628,564)
D.C. = Diversion Credit					

Key Assumptions and Related Uncertainties of Market Impact Assessment Results

Following below is a list of key assumptions and related uncertainties that should be kept in mind when interpreting the results of this market impact assessment. In all cases, the study team attempted to document the best available information and to be reasonable and conservative in the analysis.

Conversion Technology Pricing—The study's estimates about conversion technology pricing (tipping fees) and feedstock are somewhat speculative because no commercial scale facilities currently exist in California.

Conversion technology growth scenarios—Much of the study is based on a single hypothetical conversion technology growth scenario. Actual facility implementation may be very different from these assumptions, and the resulting impacts on markets will vary from our findings.

Technology—Advances in conversion technologies and capabilities and advances in sorting technologies would likely reduce the conversion technology cost structure. If those reduced costs were reflected in facility tipping fees, it could have very different results on the recycling and compost markets.

Recycling market trends—Although recycling markets are currently experiencing a period of relatively high demand and high prices, these markets will likely experience extreme volatility in the future. The impact of the export market, particularly to China, has been emphasized, but it is not known exactly when or if China will be able to develop sufficient material sources within Asia to reduce demand for materials from the United States. The United States may experience periods of extremely low recycling demand or prices in the future, and this would cause results very different from the results presented in this chapter.

Trends in Conversion Technology Ownership—Facility ownership arrangements are unknown, and the pace of conversion technology development is uncertain. If national or regional waste-hauling companies fully embrace these technologies, they may be utilized to a greater extent than market prices would dictate in order to keep facilities operating. Municipally owned facilities, if any are developed, might have similar incentives to operate at higher capacities than market prices would dictate.

Average vs. Specific Impacts on Firms—Although the results presented herein refer to the markets as a whole, the impacts on any individual firm are far more dependent on local conditions, local contracts, and management of the firm. This is especially true for smaller or more regional firms. The larger firms will have experiences that are closer to the market as a whole. In addition, any conversion technology facilities that are sited and that accept materials will have an impact on other facilities in the immediate area (within 15 to 40 miles).

Future Research Needs

The work conducted for this study suggests the following list of key areas for future research with respect to conversion technologies and their potential life cycle and market impacts:

- **Update the study results with environmental, operating, and market data from actual facilities in California and the United States, as they become available.** This study relies largely on vendor-supplied information, permit applications, and international information. New conversion technology facilities are expected to become operational in the near future, both in the State of California and in other states.

- **Analyze regions with a wider variation in waste composition.** The two regions analyzed in this study, Los Angeles and San Francisco, are both urban and have very similar waste compositions. It would be useful to analyze the conversion technologies in the context of a very different waste composition.

- **Analyze other feasible conversion technologies.** In addition to the three narrowly defined technologies included in this study, others may emerge because these three have an even wider range of practice.

- **Analyze optimal conversion technology facility configurations**. The CIWMB defined specific configurations and capacities for the hypothetical conversion technology scenario included in this study. We did not evaluate aspects such as optimal co-location of conversion technologies with existing waste management facilities, or the optimal mix of conversion technologies given a defined quantity and composition of waste.

- **Investigate the market impacts of handling other types of waste streams.** This study focuses on municipal solid wastes, as directed by CIWMB. However, other waste streams like agricultural waste, construction & demolition debris, biosolids, and wood waste could prove viable as CT feedstock.

- **Research conversion factors for plastics.** The available economic information for plastics (that is, tons to jobs and revenues conversion factors) seem to be overly inflated compared to the other factors for other materials. This results in high estimates of economic impacts of recycling and may generally skew the study results. Further research into the plastics conversion factors may result in more accurate results, if plastics data is found to be incorrect.

- **Research the potential impact of exports to China on recycling markets.** China's demand for recycled materials from California are significant, not just to this study, but to the entirety of California's recycling infrastructure. California has experienced, and will likely continue to experience, high recycling rates as a result of program implementation coupled with high demand for recyclable materials. However, China is predicted to be able to supply its own demand for recyclable materials in the next 10 to 20 years. If true, this would have large impacts on California's recycling infrastructure in the future. This is an issue that the CIWMB should revisit in future years as part of its ongoing strategic planning process.

- **Analyze small modular conversion technology facilities.** This study focused on larger regional facilities located in urban areas with access to a large waste stream. Several comments received through the public process referred to smaller, more modular facilities. These would have similar economics on a per-ton basis but broader opportunities to provide unique solutions, especially in less urban areas.

Chapter 1: Introduction

Background

New technologies to convert organic and plastic wastes to fuels and electricity are rapidly emerging. To date, one such facility is scheduled for construction in Kings County, California. The California Integrated Waste Management Board (CIWMB or the Board) recognizes that the existing recycling and composting markets for organic material utilization may not be sufficient to consume the State of California's generation of organic waste. The CIWMB is interested in the potential for these technologies to supplement existing waste management activities, should they prove to be environmentally safe.

Assembly Bill 2770 (Chapter 740, Statutes of 2002) requires the CIWMB to prepare a report on these noncombustion conversion technologies to describe and evaluate their potential market and life cycle environmental impacts. These impacts are to be compared to those associated with the existing practice of disposal in landfills, as well as waste-to-energy (WTE) combustion and mixed organic composting and recycling.

The CIWMB awarded a contract to an RTI International* (RTI) team to perform this work. RTI managed the project and was the lead on the life cycle assessment . The National Renewable Energy Laboratory prepared a materials and energy balance for selected conversion technologies and assisted RTI with the LCA. Hilton, Frarnkopf & Hobson was the lead on the market impact assessment. Boisson & Associates coordinated public input and provided advice and assistance related to study design and presentation. Separate from this study, the CIWMB contracted for a concurrent effort by the University of California at Riverside (UCR) and the University of California at Davis (UCD) to conduct a comprehensive technical evaluation of alternative conversion technologies, addressing issues relating primarily to their technical feasibility and potential environmental impacts.

Goals of This Study

In general, the research sought to answer these primary questions:

1. What are the life cycle environmental impacts of conversion technologies and how do these compare to those of existing municipal solid waste (MSW) management practices?
2. What are the economic, financial, and institutional impacts of conversion technologies on recycling and composting markets?

The goal of this research is to better understand the potential environmental and market impacts (positive and negative) that may result from the implementation of conversion technologies, as well as to identify the potential tradeoffs of using conversion technologies as alternatives to existing MSW management practices. This research is not intended to make definitive conclusions about conversion technologies.

The emphasis of this study is on conversion technologies as management alternatives for the post-recycling, unrecovered portion of the MSW stream, which is otherwise disposed of in landfills.

Conversion Technologies Studied

This study evaluated the potential environmental and market impacts of one particular hypothetical conversion technology growth scenario that involves an increase in the capacity of

* RTI International is a trade name of Research Triangle Institute.

three types of conversion technologies (acid hydrolysis, gasification, and catalytic cracking) in two California regions over seven years.

First, a life cycle assessment was performed to identify and compare the environmental impacts of the hypothetical conversion technology growth scenario with several alternative management scenarios involving landfilling, WTE, recycling, and composting. Second, a market assessment was performed to evaluate the potential impacts of the hypothetical conversion technology growth scenario on projected recycling and composting markets.

The hypothetical conversion technology growth scenario is described in detail in Chapter Two, and the methodologies for the life cycle assessment and market assessment are described in Chapters Three and Five, respectively. The need to limit the scope of the conversion technologies studied has important implications for using the study, as discussed below.

Limitations of This Study

Identifying and evaluating every possible outcome of any technology is an impossible task. This is the first study to attempt to comprehensively analyze environmental and market impacts of conversion technologies. For this reason, it was necessary to limit the analysis to one particular hypothetical growth scenario.

For this study, the conversion technologies studied do not yet exist, nor do they operate at commercial scales in the United States. Therefore, there is considerable uncertainty surrounding where the conversion technologies would be located, which specific technologies would be built, how the conversion technologies would operate, what feedstocks they would accept, and what their environmental and market impacts would be.

Furthermore, conversion technologies and proposed facilities are evolving rapidly, and much of the information regarding this evolution is proprietary. We developed approaches to the life cycle assessment and market analysis that are based on what we felt to be reasonable and conservative assumptions about conversion technologies. The methods developed and the results described in this report attempt to conduct comprehensive, order-of-magnitude assessments of potential impacts of the selected conversion technologies on the environment and recycling and composting markets. We do not attempt to make predictions about the success or actual environmental and market impacts of the conversion technologies.

Additional limitations of this study include the following:

- The feedstock composition that would be used by the conversion technologies is highly uncertain and will largely be determined through contract negotiations with local governments and private firms.
- The study is focused on the current state of practice for conversion technologies. Future technological advancements in conversion technologies were not investigated or incorporated into the assessments.
- The study focused on three specific technologies among many, whereas the companion study by the University of California focused on the world of existing conversion technologies.

A life cycle assessment is not a risk assessment. Rather, it shows the difference in total energy consumption and emissions of proposed conversion technology scenarios when compared to baseline scenarios of landfill disposal and WTE. Concentrations of pollutants at a given time and location are not captured by a life cycle assessment. A study to identify concentrations would need to be site-specific and is outside the scope of this effort. The State of California's Office of Environmental Health Hazard Assessment (OEHHA) intends to conduct a more thorough health hazard assessment of the conversion technologies, based on the information provided in this report and the companion University of California study.

The regions and number of facilities in each region were chosen to serve as hypothetical scenarios for the sake of analysis and discussion. In reality, the numbers and types of facilities that will be developed, if any, are unknown. Some assumptions could dramatically change the outcome of the study. For example, we have assumed that the preprocessing steps used by each technology recover an assumed percentage of unwanted materials (for example, metals). We make assumptions about how much of this recovered material is sent for recycling versus disposed of in a landfill.

Social issues, such as environmental justice, were not captured by this study.

These limitations are discussed more thoroughly, along with key findings, in Chapters Four and Six.

How to Use This Report

This report was designed for use by the CIWMB to assist in preparing a report to the State legislature regarding the potential environmental and market impacts of conversion technologies. It provides information to assist in understanding technical and non-technical factors and issues that may influence environmental and market impacts from the implementation of conversion technologies.

This report may be used by the CIWMB and by the public for the following applications:

- Assist in understanding the range of potential environmental and market impacts of conversion technologies.
- Help inform the debate over future State policies by providing information on the broader picture for policy analysts, government officials, and technology assessors of interactions that may affect the adoption, effectiveness, and impacts of conversion technologies.
- Provide technical support to others (for example, federal agencies, policymakers) who are involved in evaluating conversion technologies.
- Understand how one particular hypothetical growth scenario for conversion technologies might interact with the recycling, composting, and landfill markets in the Greater Los Angeles and the San Francisco Bay regions.
- Participate in debates concerning conversion technologies.

Regardless of its application, the study as presented in this document represents a first step in the complete assessment of the potential environmental and market impacts of conversion technologies. The results of this study provide assessors with the identification of areas that require further investigation, as well as guidance on the types of more detailed assessments that are needed to fully understand the likely impacts of a conversion technology. As conversion technologies become functional in the United States, additional detailed assessments will complement the results of this study.

Process for Conducting the Study

For approximately four years, the CIWMB has been examining noncombustion conversion technologies that have the potential to take materials currently disposed of in landfills and convert these materials into energy, alternative fuels, and other industrial products. The CIWMB funded this project to describe and evaluate the life cycle environmental and public health impacts of conversion technologies, as well as the impacts of conversion technologies on recycling and composting markets.

Prior to conducting the life cycle assessment and market assessment required to complete this report, detailed technical memoranda were prepared describing the processes that would be used to conduct the analyses. The draft methodologies were discussed at a focus group meeting that was hosted by the CIWMB and held in Sacramento on August 11, 2003. The technical memoranda were subsequently revised to reflect comments from both the focus group members and from the CIWMB peer reviewers.

Preliminary findings from the life cycle assessment and market assessment were issued in a draft executive summary and were presented and discussed at a workshop on April 15, 2004. Further revisions and analysis were conducted after the workshop to produce this draft report for peer review. Appendix G includes a summary of the types of comments received on the technical memoranda, as well as preliminary findings.

This report and the companion technology evaluation study performed by the University of California will assist the CIWMB in preparing a report to the State legislature that provides, to the extent possible, recommendations about the use of conversion technologies in the State.

Report Organization

This report offers a detailed evaluation of one particular hypothetical conversion technology growth scenario. It can assist decision-makers who are interested in better understanding conversion technologies by identifying the range of potential impacts and the key factors influencing those impacts. Chapter Two provides a detailed description of each conversion technology studied, as well as the key assumptions employed for the life cycle assessment and market assessment. Discussion of the life cycle assessment starts in Chapter Three, which defines the boundaries and scenarios used in the life cycle study. This is a critical step in the assessment process, because it sets the stage for gathering key pieces of information about the conversion technologies that are used to assess their environmental burdens (and benefits). Chapter Four presents the results for alternative scenarios analyzed and highlights the key findings of these results.

Chapter Five details the market impact assessment methodology. Chapter Six highlights the key findings from the market assessment. Because the conversion technologies do not exist, we structured the key findings to convey what we determined as the key aspects of the conversion technologies that would lead to impacts, rather than put forth strict conclusions about the impacts. Chapter Seven discusses key needs for future research on conversion technologies as they are constructed and operated on a commercial scale in the United States.

The appendices to this report include detailed information and data used throughout the study. The appendices include the following:

- Appendix A: Waste composition and conversion technology feedstock information.
- Appendix B: Conversion technologies materials and energy balance models.
- Appendix C: Life cycle inventory data for scenarios.
- Appendix D: Supporting life cycle inventory data.
- Appendix E: Information about RTI’s MSW DST.
- Appendix F: Market impact assessment model.
- Appendix G: Summary of public review process.

Chapter 2: Description of Hypothetical Conversion Technology Growth Scenario

This study was designed to investigate the potential impacts to the environment and recycling and mulching/composting markets due to predefined levels of implementation of concentrated acid hydrolysis, gasification, and catalytic cracking technologies in the Greater Los Angeles and San Francisco Bay regions from 2003 to 2010.

Because of uncertainties over how conversion technology facilities may evolve in California, as well as the difficulty of obtaining reliable operating data, we had to focus this study on one particular hypothetical growth scenario. This chapter describes the three selected conversion technologies and the assumed locations and growth scenarios. Narrowing the scope in this way is beneficial because it focuses the analysis exclusively on those technologies that are known to be under consideration in California and for which some data are available.

Overview of Selected Conversion Technologies

This study focused on three specific conversion technologies, including concentrated acid hydrolysis, gasification, and catalytic cracking. These technologies were chosen because they were the technologies and capacities in which local jurisdictions in California have shown particular interest, as evidenced by requests for information (RFI) being issued by California municipalities. In addition, the three chosen technologies were seen as being commercial-ready based on research conducted prior to issuance of the CIMWB’s request for proposals (RFP). The companion study performed by the University of California evaluated a more comprehensive set of alternative conversion technologies.

Brief descriptions of the concentrated acid hydrolysis, gasification, and catalytic cracking technologies are provided below. Table 1 summarizes information about the technical feasibility, feedstock compatibility, facility integration, environmental burdens, and technology development status for each technology. None of these facilities for treating MSW currently exist in the United States.

Table 1. Summary of Conversion Technology Features

Feature	Acid Hydrolysis	Gasification	Catalytic Cracking
Technical Feasibility	Yes	Yes	Yes
Feedstock Constraints	Carbohydrate fraction	Carbohydrate fraction, lignin, plastics	Polyolefin plastic only
Possible Product(s)	Ethanol Electricity, steam, lignin Gypsum	Syngas Electricity Heat	Low sulfur diesel Electricity
Environmental Impacts			
Air	Combustion emissions	Combustion emissions	Combustion emissions
Water	On-site wastewater treatment (WWT) required	Minimal	Minimal rinse water
Solid	Ash, char	Ash and char	Spent catalyst
Commercial Status	No commercial facilities Masada OxyNol received air permit for a NY facility; construction scheduled for 2004	Numerous commercial facilities (none for MSW in the United States) Large demonstration facility in Australia, closed in 2003	Facility in Poland Kings County, CA: construction scheduled for 2004 Several plastic pyrolysis plants in Europe and Asia
Model Technology Vendor	Masada	Brightstar Environmental	Plastics Energy, LLC

Concentrated Acid Hydrolysis

In acid hydrolysis, an acid (for example, sulfuric acid) is used to convert carbohydrates (for example, cellulose and hemicellulose) from waste into five- and six-carbon sugars that can be fermented into ethanol or other useful products. High (that is, greater than 90 percent) conversions of carbohydrates are possible and either concentrated or diluted acid can achieve the hydrolysis. The concentrated acid process was selected for this study because it is closer to commercialization than the diluted acid process.

The primary product from acid hydrolysis is ethanol. By-products include lignin solids, gypsum, and possibly carbon dioxide (CO_2). Lignin can be burned in a boiler to create process steam and electricity for sale or process use. Gypsum may be sold for use in a variety of processes, such as wallboard production, road bed stabilization, landfill cover, soil amendment, or land and mine reclamation. If the gypsum cannot be reused, it is landfilled. A large market exists for CO_2. Two companies, Arkenol and Masada OxyNol™, LLC, are currently commercializing concentrated acid technology. Neither company has a commercial facility, but Masada was awarded an air permit for a facility to process 230,000 tons per year (tpy) of MSW and other wastes in Middletown, NY.[1]

Gasification

In gasification, feedstock is converted to syngas, primarily carbon monoxide (CO) and hydrogen (H_2), in an oxygen-deficient atmosphere. Gasification is endothermic and requires a heat source, such as syngas combustion, char combustion, or steam. The primary product of gasification, syngas, can be converted into heat, power, or chemical products, or used in fuel cells. For this analysis, heat and power production were assumed to be the primary uses. The method of heat and power generation varies and can include gas engines, steam cycles, and complex biomass integrated gasifier combined cycle (BIGCC) systems. Numerous large-scale biomass gasifiers have been developed and have completed demonstration-scale testing and commercial deployment.

At least seven technologies were identified as commercially proven on a large scale and were considered for inclusion in this study. The State of California's definition of gasification specifies no oxygen introduction to the gasification process. This definition is very narrow and differs from the general definition of gasification in the companion *University of California Conversion Technology Evaluation Report*. The majority of existing gasification technologies include some oxygen introduction. Only the Brightstar Environmental Solid Waste Energy Recycling Facility (SWERF) technology met the State's definition and was included for further study.

Catalytic Cracking

In thermal cracking (for example, pyrolysis) or catalytic cracking, waste plastics are converted into liquid and gaseous fuels. The addition of catalysts lowers the reaction time and temperature and can increase the selectivity of the products, but catalysts are generally expensive. H.SMARTech, Inc., has developed a commercial process for the catalytic cracking of plastic wastes. After shredding, the plastic feedstock is melted and mixed with the catalyst. The gaseous products are collected and oil is condensed. The oil is distilled into diesel and gasoline. Noncondensibles (for example, propane) and gasoline are combusted in a gas turbine to provide process heat and electricity. The diesel fraction is shipped off-site.

The catalytic cracking technology is designed for polyolefin plastics (for example, grocery bags or agricultural film) and a narrow spectrum of feedstocks. Other components (for example, polyvinyl chloride [PVC]) must be removed before processing. H.SMARTech commercialized a polyolefin chemical recycling process in 1998 in Zabrze, Poland. The facility is the largest catalytic cracking plastics recycling plant in the world, with a capacity of 145,000 tpy of mixed plastics.[2] H.SMARTech formed Plastics Energy, LLC, to build a 50-ton-per-day (tpd, expected to expand to 100 tpd) facility in Kings County, California, by the end of 2004.[3] Other companies (for example, Ozmotech[4]) have plastics pyrolysis facilities in Europe and Asia.

Assumed Geographic Locations and Growth Scenarios

The life cycle assessment and market assessment were based on predefined future waste management scenarios in the Greater Los Angeles and San Francisco Bay regions. These regions and scenarios were defined by CIWMB in the RFP for the study. This hypothetical growth scenario was selected because the technologies have been considered by California jurisdictions and data were relatively available.

The growth scenario was selected to include a range from low to relatively high capacities that would assist the market assessment in evaluating the potential impacts on recycling and composting. Developing the most probable projected growth scenario for conversion technologies was not part of the study and should not be inferred from these scenarios. However, given the rapidly changing conversion technology marketplace and the lack of data, this hypothetical scenario was intended to assist the study to provide the best overview of conversion technology environmental and market issues possible at this time.

Conversion technologies were incorporated at varying capacities from the base year of 2003 to 2010, as follows:

2003 (Base Year)

- Three 500 dry tpd acid hydrolysis facilities in each region (1,500 dry tpd total).
- Four 500 dry tpd gasification facilities in each region (2,000 dry tpd total).
- One stand-alone, 50 dry tpd catalytic cracking facility in each region.

Years 2004 to 2010

- One additional 500 dry tpd gasification plant built in each region in the year 2005.
- Two additional 500 dry tpd acid hydrolysis plants built in each region in 2007.
- One additional 500 dry tpd gasification plant built in each region in 2010.

Table 2. Facility Configurations, 2003 to 2010, dry tons per day

	2003	2004	2005	2006	2007	2008	2009	2010
Acid Hydrolysis	1,500	1,500	1,500	1,500	2,500	2,500	2,500	2,500
Gasification	2,000	2,000	2,500	2,500	2,500	2,500	2,500	3,000
Catalytic Cracking	50	50	50	50	50	50	50	50
TOTAL	3,550	3,550	4,050	4,050	5,050	5,050	5,050	5,550

For purposes of this study, it was assumed that the Greater Los Angeles region includes the counties of Los Angeles, Orange, Riverside, and San Bernardino. The San Francisco Bay region was assumed to include the counties of Alameda, Contra Costa, San Francisco, San Mateo, Santa Clara, Solano, Marin, Napa, and Sonoma. The CIWMB reviewed the assumptions made regarding the location of the facilities and the potential value of including a smaller region and a rural region with more agriculture wastes. Because a large percentage of California's municipal solid waste is generated and processed within the Los Angeles and San Francisco urban areas, the CIWMB believed that the impacts of conversion technologies should be assessed within these same areas.

The base year of 2003 was selected because that was the year in which this study began and for which we had the most recent waste generation and composition data for the Los Angeles and San Francisco regions. The relevance of these geographic location assumptions are discussed in the findings chapters (Chapter Four and Chapter Six).

Transportation Distances

It is assumed that the conversion technology facilities are co-located at materials recovery facilities (MRF). Other assumed transportation distances between various facilities included in the scenarios are shown in Table 3.

Table 3. Transportation Distance Assumptions

Type of Facility	Distance (miles)[a]
Waste Management Facilities	
Collection to MRF/CT facility	15
Collection to transfer station	15
Collection to landfill or WTE or compost	15
Transfer Station to landfill or WTE or compost	45
MRF/CT or WTE or compost facility to landfill	25
Remanufacturing Facilities[b]	
Aluminum	500
Glass	200
Paper	250
Plastic	250
Steel	500

[a]These assumptions apply equally to all scenarios modeled, depending on whether or not the facilities are included in the specified scenario.
[b]The distance to remanufacturing facilities represents the transport distance from a MRF or conversion technology to the plant where recycled materials are remanufactured into new products (e.g., a paper mill).

Conversion Technology Feedstock Assumptions

Table 4 summarizes the assumed annual capacities and incoming waste needs based on the composition (see Table 5) of waste landfilled in the Greater Los Angeles and San Francisco Bay regions. The greater Los Angeles region includes the counties of Los Angeles, Orange, Riverside, and San Bernardino. The San Francisco Bay region includes the counties of Alameda, Contra Costa, San Francisco, San Mateo, Santa Clara, Solano, Marin, Napa, and Sonoma.

Landfills operate as material is brought in and are typically shut down on Sundays and holidays. Conversion technology facilities will not operate in the same manner, because it is time-consuming and economically prohibitive to shut down and bring an operating plant back on-line unless absolutely necessary. Therefore, to accommodate for this, there are a couple of days worth of storage for the waste that is brought to the plant to ensure continuous operation. We assumed that the facilities operate 90 percent of the time, with limited downtime assumed for machine maintenance and service disruptions. Based on 90 percent operating capacity, or operating 329 out of 365 days per year, we assumed the feedstock tonnage demands that are listed in Table 4.

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Table 4. Assumed Annual Capacities and Incoming Waste Needs

Technology	2003	2004	2005	2006	2007	2008	2009	2010
Wet Tons Per Year (based on 329 operating days per year)								
Acid Hydrolysis	493,500	493,500	493,500	493,500	822,500	822,500	822,500	822,500
Gasification	658,000	658,000	822,500	822,500	822,500	822,500	822,500	987,000
Catalytic Cracking	16,450	16,450	16,450	16,450	16,450	16,450	16,450	16,450
Total	1,167,950	1,167,950	1,332,450	1,332,450	1,661,450	1,661,450	1,661,450	1,825,950
Required Incoming Tonnage (Wet) Before Sorting — Greater Los Angeles Region								
Acid Hydrolysis	630,176	629,260	629,260	629,260	1,048,766	1,048,766	1,048,766	1,048,766
Gasification	737,681	734,863	918,579	918,579	918,579	918,579	918,579	1,102,294
Catalytic Cracking	1,092,230	1,092,230	1,064,427	1,064,427	1,064,427	1,064,427	1,064,427	1,064,427
Total	1,367,857	1,364,123	1,547,839	1,547,839	1,967,345	1,967,345	1,967,345	2,151,060
Required Incoming Tonnage (Wet) Before Sorting — San Francisco Bay Region								
Acid Hydrolysis	641,780	643,525	643,525	643,525	1,072,542	1,072,542	1,072,542	1,072,542
Gasification	754,643	754,475	943,093	943,093	943,093	943,093	943,093	1,131,712
Catalytic Cracking	1,078,636	1,078,636	1,118,529	1,118,529	1,118,529	1,118,529	1,118,529	1,118,529
Total	1,396,423	1,398,000	1,586,618	1,586,618	2,015,635	2,015,635	2,015,635	2,204,254

Table 5. Assumed Percent Composition of Waste Sent to Conversion Technology Facilities[a]

Component	Los Angeles		San Francisco	
	2003	2004–2010	2003	2004–2010
Paper	32.5	31.5	32.2	31.6
Plastic	11.5	11.7	10.8	11.1
Metals	7.6	7.3	9.6	9.6
Glass	3.8	3.7	3.9	3.9
Organics	42.8	43.9	41.6	41.9
Miscellaneous	1.9	1.8	1.9	1.9

[a] Construction and demolition, industrial, and hazardous waste are assumed not sent to conversion technology facilities.
Note: Values may not sum to 100 percent due to rounding.

For this study, we assumed that conversion technology facilities would be handling waste material that is currently being (and will otherwise be) sent to landfills for disposal. Because each conversion technology facility can only accept certain materials in its process, each facility employs up-front material separation activities similar to those found in a mixed-waste MRF (with the exception of a few pieces of specialty equipment, such as autoclaves and floatation separation systems). This is why the incoming amount of waste listed in Table 4 is higher than the actual amount used in the conversion technology. For this study, we assumed that 95 percent of the incoming unwanted materials were removed by the up-front separation and that 5 percent enter the conversion technology process as contaminants. Of the material removed, we assumed the split between recovery for recycling versus landfill disposal as listed in Table 6.

Table 6. Assumed Percent of Material Recovered for Recycling and Landfill Disposal[a]

Disposition	Glass	Plastic	Metals
Recovered and Recycled	50	50	70
Removed and Landfilled	45	45	25
Unremoved (Process Contamination)	5	5	5

[a]These values represent general assumptions across all conversion technologies for the removal of unwanted materials prior to the process. For example, glass and metals are removed by all of the conversion technologies studied. Plastic is removed in hydrolysis. Preprocessing for catalytic cracking involves selecting only those plastics that are suitable for the catalytic cracking process.

Detailed Conversion Technology Descriptions and Boundaries

The boundaries for each conversion technology included not only the inputs and outputs to the technology, but also the processes that supply inputs to those operations. These include the products of fuels, electricity, and materials. Likewise, any useful energy or products produced by the conversion technology system were captured by the inventory. Our goal in selecting parameters to include in the inventory was to identify all relevant inputs and outputs to each technology. No primary data collection was conducted for this study, because conversion technology facilities for MSW do not currently exist in the United States. Therefore, we relied on publicly available sources of information about planned U.S. facilities or existing foreign facilities, as well as direct communication with the technology vendors.

Process flow diagrams and descriptions were developed for the selected conversion technologies based on designs used by specific vendors: concentrated acid hydrolysis is based on the Masada OxyNol™ technology, gasification is based on the Brightstar Environmental SWERF technology, and catalytic cracking is based on the Plastics Energy LLC/H.SMARTech technology. These technologies are described in more detail below.

Concentrated Acid Hydrolysis

In acid hydrolysis, an acid (for example, sulfuric acid) is used to convert carbohydrates from waste into five- and six-carbon sugars that can be fermented into ethanol or other useful products. Acid hydrolysis is compatible with the organic (for example, yard wastes, wood wastes) fraction of the MSW feedstock. Other materials should be removed during preprocessing. Concentrated acid hydrolysis, illustrated in Figure 1, is the most complex of the three conversion technologies evaluated. This process consists of seven major process areas: feed handling, hydrolysis, acid recovery and recycling, fermentation, ethanol recovery, wastewater treatment, and power production.

The presorted feed is dried to 10 percent moisture and ground to less than 1 inch. It is then mixed with 70 percent sulfuric acid and heated. The solids are washed and separated from the sugar/acid mix. After another washing, the solids are sent to the staged-air gasifier, and the wash water is recycled in the process. The sugar/acid mix is cooled before being sent to an ion exchange column. The recovered sugar is further concentrated using a reverse-osmosis system. It is then neutralized and any solids are removed. The concentrated, cleaned sugar stream is sent on to fermentation, and the acid is sent to acid recovery.

The acid recovery system is composed of an ion-exchange bed, which will elute the acid and sugar at different times. The acid/water mix is sent to evaporation to concentrate the acid before recycling to the hydrolysis steps. The sugar solution is then neutralized with lime, any gypsum formed is separated out, and the sugar is sent to fermentation. Ethanol is recovered from the fermentation product stream via distillation and dehydration.

Non-MSW inputs to the process are water, sulfuric acid, lime, denaturant (gasoline), ammonia, and catalysts. The process generates all of its own heat, steam, and electricity. Outputs consist of the ethanol and electricity products; volatile organic compound (VOC) emissions from storage; combustion emissions; and ash, gypsum, treated wastewater, and spent catalysts. The staged air gasifier will require air pollution control. Ammonia injection was assumed for control of nitrogen oxides (NO_x). The ethanol and denaturant storage tanks may also require controls to minimize losses.

Inert feedstock constituents for acid hydrolysis include glass, plastics, and metals. In addition, lignin and other noncarbohydrate fractions of the MSW will not be converted to ethanol.

Hydrolysis technologies have air, solid, and water releases. Air emissions are generated primarily from lignin combustion, with small amounts of ethanol emitted from the fermentors, storage tanks, and distillation columns. Concentrated acid hydrolysis will generate large quantities of gypsum, which may be sold, depending on market conditions. In some cases, the plant would have to pay to haul the excess gypsum away. If lignin is combusted on-site, ash will also be generated for disposal. Wastewater releases will occur from boiler and cooling tower blow down, as well as process wastewater. Due to the relatively high potential biological oxidation demand (BOD) content of the process wastewater, it is treated on-site before release to a publicly owned treatment works (POTW).

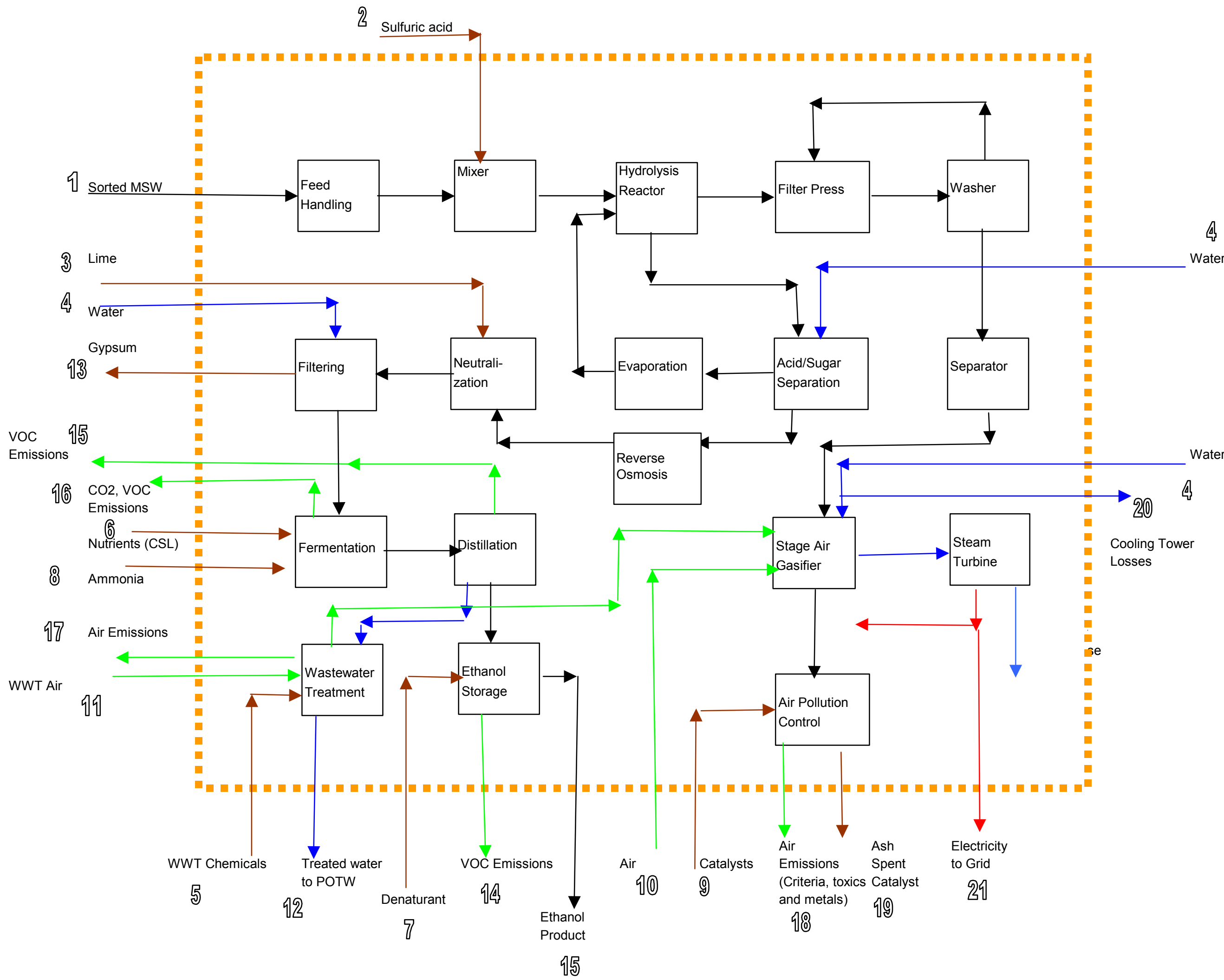

Figure 1. Concentrated Acid Process Flow Diagram
The process flow diagram shows only major process areas; for simplification, not all internal process streams are shown. The boundary of the technology is noted by a dotted line, with all streams crossing this line representing a life cycle material or energy input or output.

Gasification

In gasification, the feedstock is converted to syngas, primarily CO and H2, in an oxygen-deficient atmosphere. Gasification is compatible with the organic fraction (e.g., yard wastes, wood wastes) and plastic fraction of the MSW feedstock. Metals, glass, and other recyclables should be removed in the MRF. Power produced by the facility can be readily integrated into the power grid.

The process for waste gasification is illustrated in Figure 2 and described below. Following preprocessing in the adjacent MRF, the feedstock is sent to the main gasification area. Where the feedstock is heated, pyrolyzed, and reformed into syngas, bio-oils, and char. The char is recovered from the other products via a cyclone, cooled with a water quench, and sent off-site.

The syngas and bio-oils are scrubbed and cooled to recover the bio-oil. Heavy bio-oils and some of the syngas are recycled to the reformers, where they are combusted to fuel the reformer. The majority of the syngas and the light bio-oils are combusted in reciprocating engines to generate electricity. Waste heat from the engines is converted to steam and hot water for use in the process and for export to MSW processing (that is, the autoclave). The engine exhaust will be subject to air pollution controls. At a minimum, CO, NO_x, and VOC controls will likely be required. For large facilities (for example, greater than two megawatts [MW]) such as the one proposed, a combination oxidation catalyst and selective catalytic reduction (SCR) is used.

Process inputs are composed of MSW, combustion air, water, ammonia, and catalysts. Electricity, wastewater, spent catalysts, char, emulsified bio-oil, and combustion emissions are the process outputs.

Gasification produces air pollutants (for example, NO_x) and greenhouse gases (for example, CO_2) from the gas engines and the reformer; however, all emissions are expected to be controlled with SCR and oxidation catalysts. Air toxics such as metals and dioxins are expected to be minimal. In fact, all air pollutant concentrations in the exhaust gas from the reciprocating engines at the Brightstar Wollongong facility in Australia are at or below the European Waste Incineration Directive.[5]

Ash and char will also be generated. Toxicity Characteristic and Leaching Procedure (TCLP) data from refuse derived fuel (RDF) combustion ash and gasification by-products showed results that were significantly below applicable limits.[6,] Wastewater releases (for example, boiler blow down) will be minimal. The Brightstar gasifier in Wollongong was licensed for 30,000 tpy MSW.[8] It has not yet achieved its nameplate capacity, but has operated as a demonstration plant for about two years.[9]

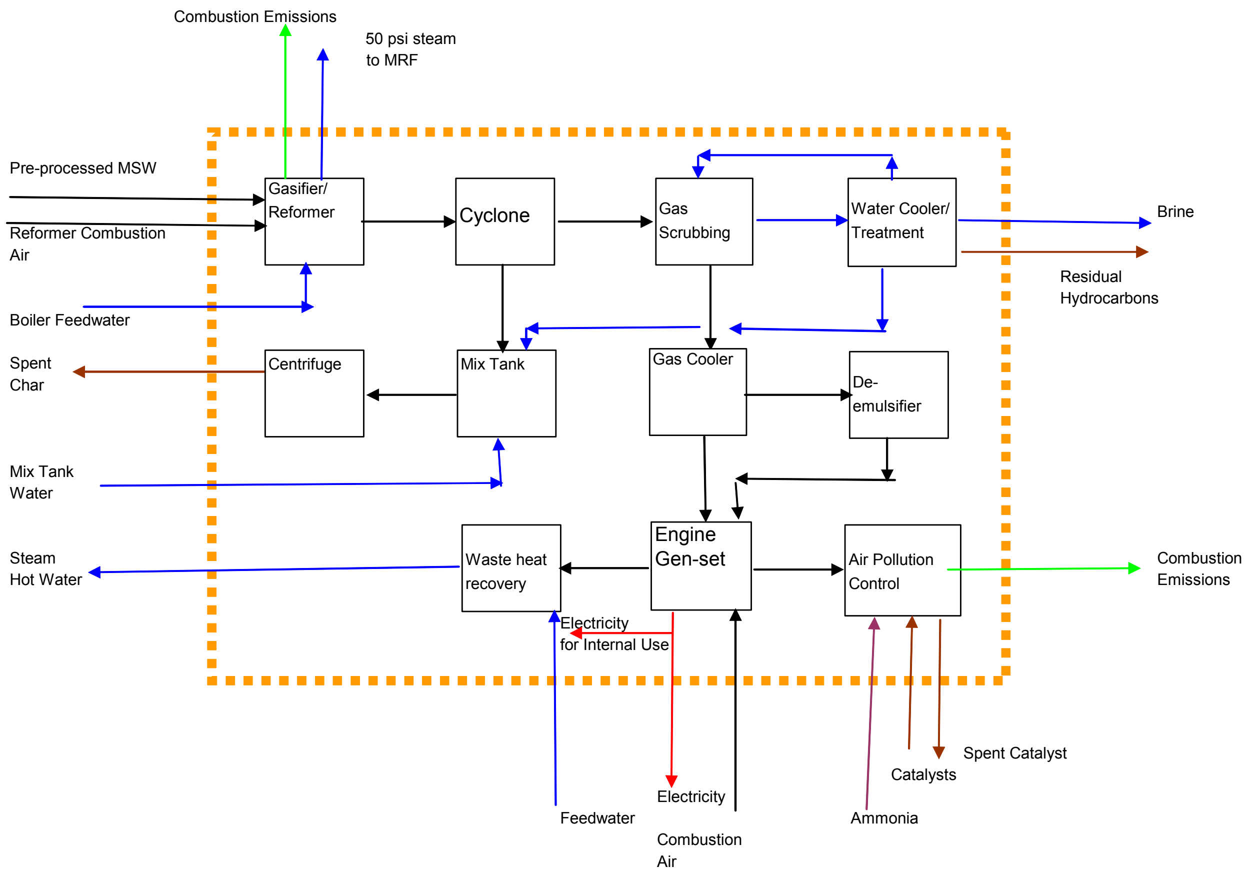

Figure 2. Gasification Process Flow Diagram
The process flow diagram shows only major process areas; for simplification, not all internal process streams are shown. The boundary of the conversion technology is noted by a dotted line, with all streams crossing this line representing a life cycle material or energy input or output.

Catalytic Cracking

In thermal cracking (for example, pyrolysis) or catalytic cracking, waste plastics are converted into liquid and gaseous fuels. Specific plastics can be sourced from existing MRFs or from sites that have source-separated plastics, such as plastic film.

The major process areas for catalytic cracking are shown in Figure 3 and include feed handling, cracking, distillation, and power production. Baled plastics are sent to a feed shredder to reduce the material to less than 3 inches. The material is then cleaned with water and dried. Wastewater from the washing step, containing primarily dirt and paper, is collected and sent off-site to a POTW. The shredded and cleaned feed is then sent to a vessel, where it is heated to 185^{o} C to melt the plastic.

The melted plastic is mixed with catalyst and reacted in the cracker. Cracked gas components leave the reactor and are sent to the distillation area. The liquid fractions (diesel and gasoline) are condensed and separated via distillation. The diesel fraction is sent to product storage, and the gasoline fraction is sent to the gas turbine, along with the light ends (for example, butane and propane) from the cracking process. Plastics Energy, LLC, used the H.SMARTech process and a proprietary metal silicate catalyst to crack the plastics, resulting in yields of 83 percent for diesel, 14 percent for gasoline, and 3 percent for light gases.[10]

The rest of the process is similar to a gas turbine facility. The gaseous and gasoline fractions are combusted in the turbine to generate electricity. The hot exhaust gas from the turbine is used to provide process heat. SCR reduces NO_x emissions in the turbine exhaust and will require ammonia injection and an SCR catalyst.

As shown in the diagram, the system has only three inputs besides the feedstock: catalyst, water, and air. The cracking catalyst is a metal silicate and its exact formulation is proprietary. The SCR catalyst may be a zeolites or vanadium-based catalyst. The process is almost self-sufficient in energy, requiring only 500 kilowatts (kW) from the grid.

In addition to the diesel and electricity products, the process results in combustion emissions (criteria pollutants and toxics), VOC emissions from organic storage and drying operations, wastewater, and spent catalysts. The largest source of air emissions occurs from the gas turbine, but these emissions should be well below acceptable limits because of the clean fuel. Limited amounts of miscellaneous organic air emissions will also likely occur from other processing points (for example, valves, storage tanks). Wastewater releases are low and are composed of rinse water and cooling tower blow down. Solid waste, composed of feedstock inerts and spent catalyst, is also generated.

Yield losses can occur from inert fillers or pigments. The catalytic cracking technology is designed for a narrow spectrum of feedstocks (polyolefin plastics, for example, grocery bags). Other components (for example, polyvinyl chloride or PVC) must be removed in the MRF before processing. Although the technology is narrowly focused, this waste stream currently has limited other recycling avenues.[11]

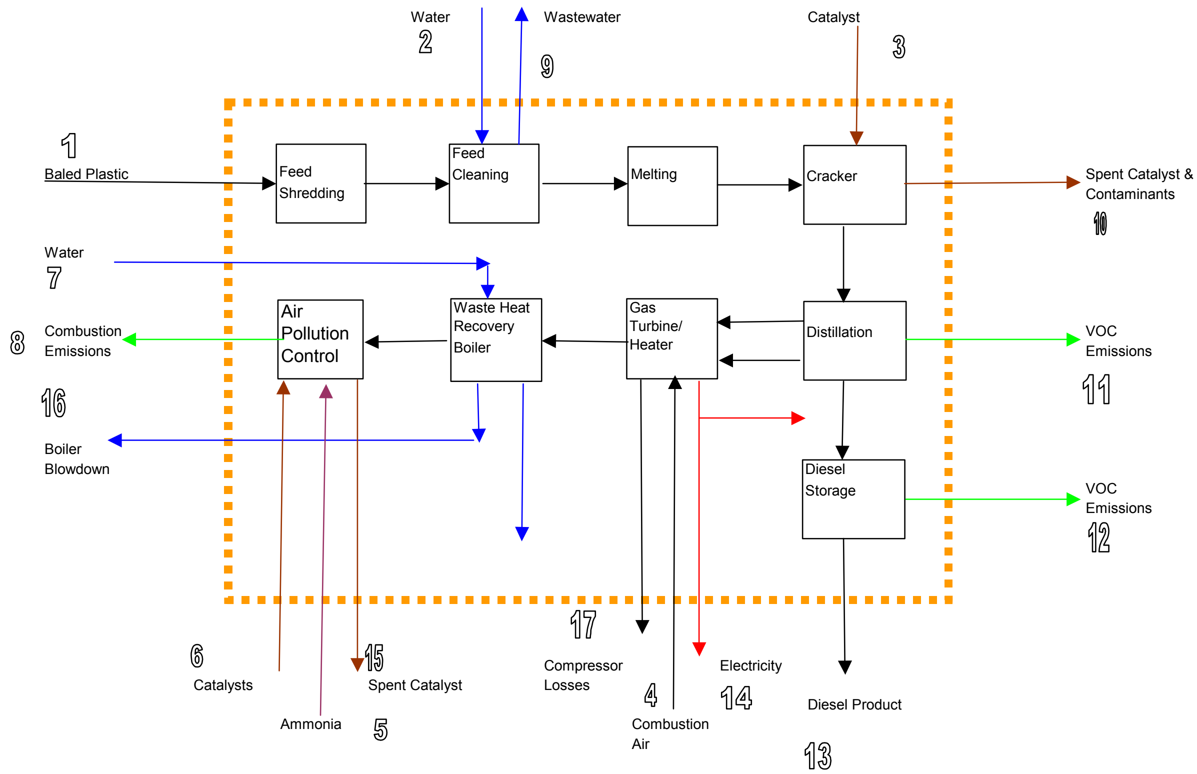

Figure 3. Plastics Catalytic Cracking System Diagram
The process flow diagram shows only major process areas; for simplification, not all internal process streams are shown. The boundary of the conversion technology is noted by a dotted line, with all streams crossing this line representing a life cycle material or energy input or output.

Boundaries for the Life Cycle Analysis

All activities that have a bearing on the management of MSW, from collection through transportation, recovery and separation of materials, treatment, and disposal, were included in the life cycle assessment. We assumed that MSW enters the system boundaries when it is set out for collection; thus, the production of garbage bags, garbage cans, and recycling bins were not included in the study. Similarly, the transport of waste by residents to a collection point (for example, drop-off facility) was not included.

The functional elements of MSW management include numerous pieces of capital equipment, from refuse collection vehicles to balers for recycled materials to major equipment at combustion facilities. Resource and energy consumption and environmental releases associated with the operation of equipment and facilities were included in the study. For example, energy (fuel) consumed during the operation of waste collection vehicles was included in the study. We included in the study electricity consumed for operation of the office through which the vehicle routes are developed and the collection workers are supervised. Activities associated with the fabrication of capital equipment, however, were not included.

For material and energy inputs to various processes, the resource and energy consumption and environmental releases associated with producing the material and energy inputs were included in the study. For example, the resources and environmental releases associated with the production of acid for acid hydrolysis were included in the study, as well as the production of diesel fuel consumed by collection vehicles.

Where a material was recovered and recycled, the resource and energy consumption and environmental releases associated with the manufacture of a new product were calculated and included in the study. We assumed closed-loop recycling processes. These parameters were then compared against parameters for manufacturing the product using virgin resources to estimate net resource and energy consumption and environmental releases. This procedure was also applied to energy recovery from other unit processes, including WTE combustion, conversion technologies, and landfill gas recovery projects.

Another system boundary was set at the waste treatment and disposal. Where liquid wastes are generated and require treatment (usually in a publicly owned treatment works), the resource and energy consumption and environmental releases associated with the treatment process were included. For example, if BOD is treated in an aerobic biological wastewater treatment facility, then energy is consumed to supply adequate oxygen for waste treatment. If a solid waste is produced that requires burial, energy is consumed in the transport of that waste to a landfill during its burial (for example, bulldozer) and after its burial (for example, gas collection and leachate treatment systems) in the landfill. Also, where compost was applied to the land, volatile and leachate emissions were included in the study.

Boundaries for the Market Impact Assessment

To conduct the market impact assessment, we chose a theoretical number of facilities to come on line over the course of several years. We chose three technologies, and CIWMB specified facility sizes. The choices were made in order to simulate significant impacts on the markets studied as a result of different technologies, as well as to understand the different impacts that different technologies would have on the markets. The actual number, size, location and technology of facilities that may be built in the future is unknown.

The two largest regions in California (in terms of population and waste generation) were chosen for this study in order to illustrate what might happen if conversion technology facilities were located in the two regions. If other regions had been the subject of study, the results of the MIA study may have been different, but the results of the life cycle assessment would not change significantly.

The existing markets studied in the two regions included paper and plastics recycling, composting and mulching, and the use of such products as alternative daily cover (ADC) for green waste, and the landfill markets. Other recycling markets, such as those for metals and glass, were not specifically targeted in this study, although some study results do briefly address those materials. Potential impacts on the biomass-to-energy market were also included in this study.

Except where noted, we assumed that jurisdictions would continue to adhere to existing practices. These practices include existing contractual arrangements for waste collection and disposal, existing recycling and green waste collection programs, implementation of diversion programs as specified in their adopted source reduction and recycling elements (SRRE), and the fulfillment of commitments with the CIWMB in SB 1066 time-extension or alternative diversion requirement agreements.

The waste streams considered for this study, except where noted, were the materials that are currently being landfilled in the two regions. Other materials that are generally outside the purview of the CIWMB, such as agricultural waste, were not included in this study.

We generally assumed co-location of conversion technology facilities with MRFs. However, transportation economics were not modeled because the exact location of conversion technology facilities is unknown. We also assumed that construction and demolition (C&D) debris and household hazardous waste materials would not be directed to conversion technology facilities; also, that mixed waste materials would need preprocessing for gasification and acid hydrolysis in order to remove materials that reduce the efficiency of the process (that is, metals and glass.)

Chapter 3: Life Cycle Assessment Methodology

AB 2770 included the requirement that the CIWMB's report on conversion technologies "describe and evaluate the life cycle environmental and public health impacts of conversion technologies and compare them with impacts from existing solid waste management." To meet this requirement, a life cycle assessment was conducted for the selected conversion technologies.

Our general approach to complete the life cycle assessment included the following steps:

1. Defining the scope, boundaries, and specific process steps for the acid hydrolysis, gasification, and catalytic cracking technologies.
2. Developing materials and energy balance models for each conversion technology.
3. Constructing life cycle inventory modules for each conversion technology by adding life cycle burdens and benefits to the materials and energy balance models.
4. Applying RTI's Municipal Solid Waste Decision Support Tool (MSW DST) to calculate the full life cycle inventory for the conversion technologies scenarios (from the collection of waste to its ultimate disposition), as well as for existing waste management practices, including recycling, composting, WTE combustion, and landfill disposal.

This section describes the details of the life cycle assessment that was performed and presents and discusses the findings. The section begins with background information about life cycle assessment and its application to MSW management alternatives analysis. It covers the construction of the life cycle inventory for the conversion technologies system. Finally, this section presents the results of the inventory, comparing and contrasting the conversion technologies to existing practices.

What Is Life Cycle Analysis?

Life cycle analysis is a term used to describe a type of systems analysis that accounts for the complete set of upstream and downstream energy and environmental impacts associated with production systems. The life cycle concept and more formal analysis framework have evolved through an increasing awareness that a comprehensive view of production systems leads to environmentally friendly design and decision making. The process for conducting a life cycle analysis has been recently standardized by the International Standards Organization (ISO) and provides a useful framework and methodology for estimating and comparing the environmental performance of systems. The following ISO standards are available:

- ISO 14040: Environmental Management—Life Cycle Assessment—Principles and Framework (1997).
- ISO 14041: Environmental Management—Life Cycle Assessment—Goal and Scope Definition and Inventory Analysis (1998).
- ISO 14042: Environmental Management—Life Cycle Assessment—Life Cycle Impact Assessment (2000).
- ISO 14043: Environmental Management—Life Cycle Assessment—Life Cycle Interpretation (2000).

Although these standards provide requirements and recommendations in terms of what a life cycle analysis should include, they recognize that the actual methods used and the level of detail employed in the assessment will vary by study. In general, the goals of the analysis will drive the level of complexity and detail required in the study.

The analysis methodology can contain the following steps:

1. **Goal and Scope Definition.** Defining the purpose, intended application, and intended audience for the life cycle analysis, as well as the depth and breadth of the analysis and the level of detail that is required to meet the stated goals.

2. **Inventory Analysis.** Compiling the inputs and outputs across the entire life (that is, cradle-to-grave) of the system.

3. **Impact Assessment.** Assessing the potential impacts of the inventory inputs and outputs to the environment and human health.

4. **Interpretation.** Evaluating the results of the inventory analysis and impact assessment in the context of the study goals and objectives.

The defining feature of life cycle analysis is that it captures multimedia environmental and human health impacts associated with upstream and downstream stages of a process. This feature enables analysts to assess not only the total environmental and human health profile of a system, but also to identify where impacts may be lessened through things such as process or design changes. Life cycle approaches shift environmental management from traditional “end-of-pipe” or “gate-to-gate” approaches to a more proactive and preventive approach.

In this study, we took the LCA through the inventory analysis stage only, abiding by the ISO standards cited above. The Office of Environmental Health Hazard Assessment will be conducting a detailed risk assessment of the conversion technologies upon completion of this study. The aim of this study was to identify and evaluate the general life cycle environmental performance of the conversion technologies and to compare them to reference waste management options (for example, recycling, composting, WTE, landfill).

Why Take a Life Cycle Approach to Evaluate Conversion Technologies?

A life cycle perspective encourages planners and decision makers to consider the environmental aspects of the entire waste management system. These include activities that occur outside of the traditional framework of activities, from the point-of-waste collection to final disposal. For example, anyone evaluating options for recycling should consider the net environmental benefits (or additional burdens), including any potential displacement of raw materials or energy. Similarly, when energy is recovered through waste combustion, conversion technologies, or landfill gas-to-energy, the production of fuels and the generation of electricity from the utility sector is displaced.

In this respect, life cycle analysis can be a valuable tool to ensure that a given technology creates actual environmental improvements rather than just transfers environmental burdens from one life cycle stage to another or from one environmental media to another. This analysis is also useful for screening systems to identify the key drivers behind their environmental performance.

General Approach for Applying Life Cycle Analysis to Conversion Technology Systems

A life cycle inventory analysis was applied to assess the environmental performance of a hypothetical conversion technology growth scenario when compared to several alternative management scenarios involving landfill disposal, recycling, composting, and WTE. Our general approach was to develop inventory modules for the acid hydrolysis, gasification, and catalytic cracking systems and to utilize RTI's existing MSW DST to capture the other life cycle components. These other components include waste management (for example, collection, transfer, materials recovery, compost, WTE, landfill), energy production, transportation, and materials production activities. The data and models in the MSW DST have been developed for the U.S. Environmental Protection Agency (U.S. EPA) during the past 10 years and have been extensively peer and reviewed for quality assurance. (See Appendix E for more information about the MSW DST).

Using the general decisions and assumptions employed in the MSW DST as a starting point, we defined boundaries, life cycle inventory items, and impacts that were specific to conversion technologies and consistent with those defined for the overall waste management system in the MSW DST. In addition, by using the MSW DST to capture the non-conversion technology components of the system, we were able to place more emphasis on defining conversion technology processes and collecting necessary data.

Information about RTI's MSW DST is provided in Appendix E.

Goals and Scope Definition

The goal and scope-definition phase of the life cycle analysis is crucial for designing a study that is meaningful and useful for decision making. The goals, approach, and methodology for the analysis of conversion technologies has been defined using our knowledge and experience with life cycle analysis and MSW systems and refined based on comments from the focus group meeting, peer review, and subsequent discussions with the CIWMB. This section includes a summary of goal and scope-definition components that are to be defined according to ISO 14040.

Goals of the Life Cycle Analysis

The overall goal of the analysis is to estimate the impacts that conversion technologies have on the environment and public health. In general, the analysis will seek to answer questions in two categories:

- What are the environmental and public health impacts of conversion technologies?
- How do the environmental and public health impacts of conversion technologies compare to existing MSW management practices (for example, recycling, composting, WTE combustion, landfilling)?

The goal of the life cycle analysis is not necessarily to make definitive conclusions about conversion technologies or the environmental preference of conversion technologies compared to existing MSW management options. Rather, the goal is to better understand the potential environmental and human health impacts that may result from the commercialization of conversion technologies, the tradeoffs of employing conversion technologies as alternatives to existing MSW management practices, and the variables that influence the potential environmental impacts of conversion technologies.

The analysis is being carried out by mandate of Assembly Bill 2770 (Chapter 740, Statutes of 2002), which requires the CIWMB to conduct an environmental, human health, and market impact assessment of conversion technologies. The CIWMB specified in its RFP that the approach to be used to assess the environmental and human health impacts be life cycle analysis. The intended audience for this study is the State of California policymakers, as well as state and local solid waste planners and decision makers.

System Function and Functional Unit for the Life Cycle Study

The function of a conversion technology system is to transform municipal solid waste or specific components of MSW into energy and useful products. The functional unit is the management of a given quantity and composition of MSW, as defined by the region under study. For example, the functional unit of the life cycle study in 2003 for the Greater Los Angeles region is the management of 1,367,857 wet tons of MSW. This equates to a total dry weight capacity of 3,550 tpd for the hypothetical conversion technology scenario in the Greater Los Angeles region in 2003.

The functional unit is the quantity of waste collected and processed based on defined conversion technology capacities for each region (Los Angeles and San Francisco) and each model year (2003, 2005, 2007, and 2010). See Table 2 in Chapter Two of this report for a quick summary of the conversion technology capacities for the different study years.

General Boundaries for the Life Cycle Analysis

Figure 4 illustrates the overall life cycle system boundaries for a conversion technology system. In the figure, the boundaries include not only the conversion technology and other MSW management operations, but also the processes that supply inputs to those operations, such as fuels, electricity, and materials production. Likewise, any useful energy or products produced from the conversion technology system are included in the study boundaries as offsets. An offset is the displacement of energy or materials produced from primary (virgin) resources that results from using secondary (recycled) energy or materials.

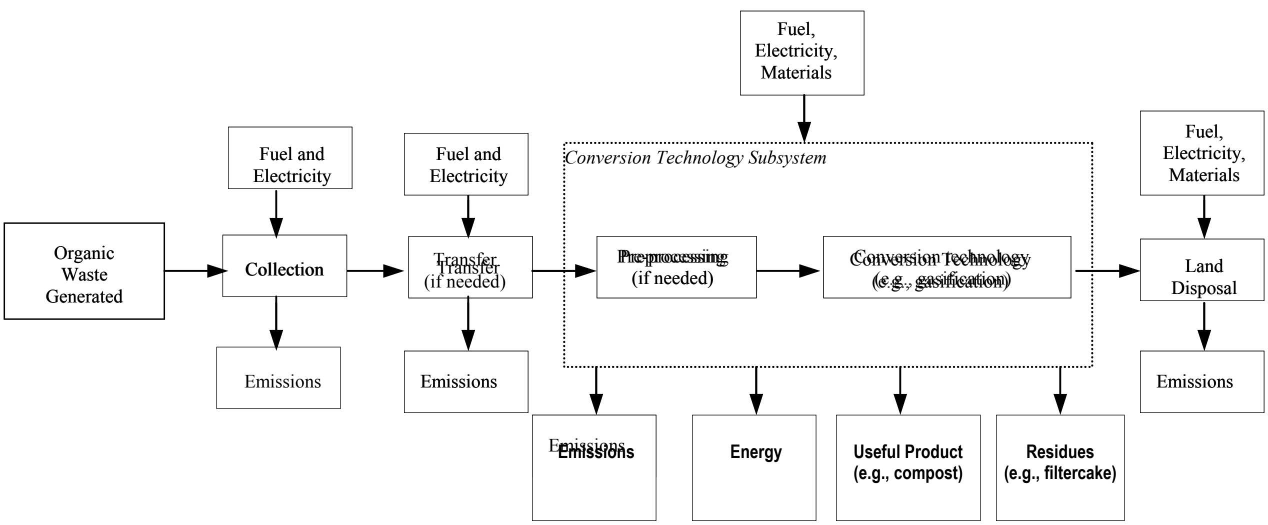

Figure 4. General Life Cycle Boundaries for a Conversion Technology System.

Once the specific conversion technology designs were identified based on the technical evaluation of technology vendors, detailed process descriptions and process flow diagrams were prepared to identify mass flows, energy consumption, environmental releases, and other significant waste production and resource utilization parameters. An important aspect of this step was identifying the key aspects (for example, facility construction and operation parameters) of each process that needed to be considered and ensuring that all conversion technology systems were defined in a consistent manner. For example, if one conversion technology system included the production of materials used for pollution control, then all conversion technology systems should include this aspect. In the case of defining the conversion technologies, we thought highlighting any waste preprocessing steps (for example, separation, shredding) that may be required was critical.

The system boundaries were largely based on the mass flow of materials and energy in and out of the different unit processes included in the system. The collection, transfer, and residue disposal steps were modeled so that they were the same for all technologies evaluated, unless the technology required a special process to replace the steps. The conversion technology and any necessary preprocessing steps were then modeled independently and added to the collection, transfer, and disposal processes.

The main categories of inputs and outputs that were compiled for each conversion technology system are consistent with those that RTI includes in its MSW DST. These include annual estimates for energy consumption, air emissions, water pollutants, and solid waste. In deciding upon which LCA burdens to include in the analysis, we decided to focus on criteria pollutants.

In comparing conversion technologies to existing MSW management practices, we needed to have consistent data for each burden (for example, dioxin/furan emissions) across all unit processes in the waste management system. Therefore, if data for any given burden was not consistently available across all processes included in the system, then the burden was not included in the comparative results of conversion technologies to existing management practices. However, we did consider all burdens in this report when describing specific conversion technologies.

Life Cycle Inventory Modules for Conversion Technologies

The purpose of the life cycle inventory is to collect data in order to quantify the relevant inputs and outputs of a system. The process of conducting an inventory is iterative. As data are collected and we learn more about the system, new data requirements or limitations may be identified that necessitate the redrawing of system boundaries, a change in data collection procedures, or modification of study goals and scope.

The goal of our data collection effort for the inventory was to ensure that appropriate data were collected to support the goals of the study. Through previous work conducted by RTI, extensive life cycle data have already been collected or developed for waste management processes and are available for use in this study.

RTI's existing data include energy consumption; air emissions; water effluents; solid waste for waste collection; transfer stations; materials recovery facilities (MRF); yard and mixed municipal waste composting; WTE combustion; landfill disposal; and supporting life cycle operations of electrical energy production (using national, regional, or user-defined grids), fuels production for example, diesel fuel), virgin and recycled materials productions (for example, glass containers), and transportation (for example, over-road haul). RTI's data have been carefully documented to ensure transparency and thoroughly peer-reviewed. Most importantly, the RTI data allowed us to focus on collecting or developing comparable data for conversion technologies. These documents are available from RTI upon request.

Based on the conversion technology system boundaries, we collected, reviewed, and compiled data. We worked with the internal and external contacts to identify available data for each of the conversion technologies. These data were used to develop emission/energy factors and cost functions for use in conducting the life cycle inventory and for the market inventory analysis.

Data were collected from the following sources:

- Technology vendors.
- Publicly available literature.
- Federal reports.
- State and municipal governments.
- Industry reports.
- Trade associations.
- Waste collection, processing, and disposal facility records and reports.
- Previous studies (for example, National Renewable Energy Laboratory [NREL] biogas study).

In 2002, RTI conducted a literature review for the CIWMB to identify potential public sources of life cycle data for conversion technologies; however, only limited data were found. For this study, we went directly to the technology vendors to collect the necessary data to complete the LCI. We supplemented the information obtained from the vendors with additional data from public sources. For a number of activities (for example, front-end loader operation) or materials (for example, fuel for vehicles and equipment), we were able to use data developed as part of the MSW DST. In addition, we used data from the Ecobalance TEAM life cycle assessment software for items for which we did not currently have inventory data. TEAM is a software model that allows users to build inventory models for different processes.

The items for which data was obtained from TEAM include the following:

- Ammonia production (used for air pollution control).
- Sulfuric acid production (material input to acid hydrolysis).
- Methyl tertiary-butyl ether (MTBE) production (offset of hydrolysis-produced ethanol).
- Gypsum production (offset of hydrolysis-produced gysum).

Material and Energy Balance Models

The scope and boundaries for each conversion technology are partially depicted by the accompanying process flow diagrams presented in Chapter Two of this report. Each process flow diagram shows the major process steps that occur in processing and converting waste input. In addition, the diagrams show the main material and energy inputs and outputs for each conversion technology. For example, the diagram for acid hydrolysis shows that acid is a main material input to the process. Likewise, ethanol is a main energy output of the hydrolysis process.

As shown by the process flow diagrams, the process for which data are presented are not cradle-to-grave, but rather gate-to-gate. This is because the conversion technologies by themselves are just one process step within the system. The conversion technologies were modeled using a commercial process engineering tool called ASPEN-Plus to obtain the material and energy balance information around the process. Only after all of the pieces of life cycle inventory data from each process step within the system boundaries are assembled can a full inventory module for each conversion technology be completed.

The detailed material and energy balance model for each conversion technology are included in Appendix B. The following section describes how the results from these material and energy balance models were used to construct inventory modules for each conversion technology.

Life Cycle Inventory Modules

To calculate the inventory coefficients (energy consumption and environmental releases) for the conversion technologies, inventory modules were developed for the concentrated acid hydrolysis, gasification, and catalytic cracking systems. These inventory modules rely on the material and energy balance models from the conversion step as a starting point and then add the inventory information for upstream and downstream steps.

In general, the construction of the life cycle inventory module for each conversion technology is depicted as follows:

Materials and Energy Balance + LC input/output burdens – Offsets = Net LCI Coefficients

For example, acid hydrolysis uses sulfuric acid as a process input. The amount of acid consumed for a given tonnage of waste processed is calculated in the material and energy balance model. This amount is multiplied by the environmental burdens associated with producing the acid and added to the inventory for the technology. Similarly, the acid hydrolysis process generates some residual waste that is landfilled. The environmental burdens associated with the landfilling of these residuals is added to the inventory for the technology.

Material and energy offsets are netted out of the LCI. In the case of acid hydrolysis, the main product is ethanol. Ethanol has a number of possible uses for this ethanol. We assumed that it would be used as a replacement to MTBE as a fuel additive; therefore, the offset associated with acid hydrolysis is the production of MTBE. The quantity of ethanol that is produced by the process (as given by the material and energy balance model) is converted to an equivalent function amount of MTBE. That amount of MTBE offset is then multiplied by the inventory burdens associated with MTBE production, and these burdens are netted out of the inventory for the technology.

Treatment of Material and Energy Recovery

There are different ways to model recycling systems within the LCI framework. Two basic concepts for modeling recycling systems are open-loop recycling and closed-loop recycling. Limited recycling, such as the recycling of a newspaper into a folding carton that is not recycled, is referred to as “open-loop” recycling. Repeated recycling, such as the recycling of an aluminum can back into another aluminum can, is called “closed-loop” recycling. Theoretically, closed-loop recycling can occur a large number of times because the aluminum does not degrade with repeated recycling steps. The type of recycling model that is appropriate for a material depends not only on infrastructure for collecting and transporting post-consumer materials, but also on the physical properties of the material being recycled.

In an open-loop system, the energy requirements, environmental emissions, and raw materials for primary material acquisition/processing and disposal are generally allocated equally among the products produced (that is, the primary raw material energy requirements for the initial product are divided by the total number of product sets produced). For folding boxes made from old newspaper, half of the raw material energy, emissions, and materials are allocated to the primary material and half to the secondary material. Likewise, half of the energy, emissions, and materials for reprocessing are allocated to the primary material and half to the secondary material. This, in effect, links the primary and secondary material production systems and shows the overall LCI results for the combined system.

In a closed-loop system, recycling of the same material occurs over and over, theoretically permanently diverting it from disposal. At the ideal 100 percent recycling rate, the energy requirements and environmental emissions for primary raw material acquisition and processing become negligible, and only the data for collecting postconsumer material and reprocessing it into a secondary material is considered.

We assumed a closed-loop recycling system for all materials recovered for recycling in this study. For example, this means that when ferrous metal is recovered and recycled, it is used to produce "new" steel. Likewise, if polyethylene terephthalate (PET) plastic is recovered and recycled, it is assumed to be used to make new PET. The implication of this assumption is that the results could change if a different recycling or reuse pathway was chosen for a given material. It is not possible to indicate whether the results would be greater or less unless each possible pathway was analyzed; however, we applied the closed-loop recycling assumption across all scenarios, and therefore they are treated equally and are comparable.

For energy-related offsets, we assumed that electrical energy produced from landfill gas-to-energy, WTE, and conversion technology systems displaces electrical energy produced from fossil sources. The exact mix of fossil fuels displaced is based on the Western States Coordinating Council (WSCC) grid mix. Electrical energy is produced from the gasification and acid hydrolysis technologies.

For acid hydrolysis and catalytic cracking technologies, fuels are also produced. Acid hydrolysis produces ethanol as its main product. We assumed, based on guidance from the CIWMB, that the ethanol displaces the production of MTBE. Catalytic cracking produces a low-sulfur diesel fuel, and we assumed that the low-sulfur diesel fuel displaces petroleum-based diesel fuel.

Items Excluded from the Life Cycle Inventory

A number of items have been excluded from the life cycle inventories because they are typically found to be negligible in terms of the inventory totals. These items are described below.

The energy and environmental burdens associated with the manufacture of capital equipment is not included in the life cycle profiles. This includes equipment to manufacture buildings, motor vehicles, and industrial machinery. The life cycle burdens associated with such capital equipment generally, for a ton of materials, becomes negligible when averaged over the millions of tons of product that the capital equipment manufactures compared to the burdens associated with the processing steps.

The fuels and power consumed to heat, cool, and light manufacturing establishments are omitted from the calculations. For most industries, space conditioning energy is quite low compared to process energy. Energy consumed for space conditioning is usually less than 1 percent of the total energy consumption for the manufacturing process.

The energy associated with research and development, sales, and administrative personnel or related activities have not been included in this analysis.

For each system evaluated, small amounts of miscellaneous materials are associated with the processes that are not included in the life cycle inventory results. Generally these materials make up less than 1 percent of the mass of raw materials for the system. For example, the use of biocides and other conditioning chemicals for cooling water are not documented and included in the inventory results, except to the extent that these materials contributed to waterborne emissions from the facilities.

Life Cycle Inventory Parameters Tracked and Reported

The main categories of life cycle inventory inputs and outputs that were tracked and reported as part of this study include annual estimates for the following:

- Energy consumption.
- Air emissions.
- Waterborne pollutants.
- Residual solid wastes.

Descriptions of what comprises each of these main categories are provided in the following sections.

Energy Consumption

Annual energy consumed is aggregated across process and transportation steps in the life cycle of each conversion technology module. All fuel and electrical energy units are converted to British thermal unit (Btu) values. Electricity production assumes the average U.S. conversion efficiency of fuel to electricity and accounts for transmission and distribution losses in the power lines. Therefore, the kWh value is the aggregated amount of electricity used by the system, as delivered to the various facilities in the life cycle. The Btu value accounts for the average mix of fuels (for example, coal, natural gas, hydroelectricity, nuclear) used by utilities to produce electricity in the United States.

Where energy is produced by a process and displaces the production of electricity or a fuel by a utility or the petroleum sector, respectively, such as the combustion of MSW with energy recovery, a credit is given to the extent that it displaces power generation by the utility sector or production of the fuel. For this study, we used the WSCC grid mix to calculate the life cycle inventory burdens associated with electrical energy consumption, as well as the credits associated with electrical energy offsets. The WSCC grid uses the following mix of fuels:

- 41 percent coal.
- 15 percent natural gas.
- 0.4 percent oil.
- 12.8 percent nuclear.
- 29.5 percent hydroelectric
- 1.3 percent wood.

Air Emissions

Air emissions can result from two primary sources in the life cycle: process-related activities or fuel-related activities. Process emissions are those that are emitted during a processing step, but not as a result of fuel combustion. For example, the calcining of limestone to produce lime emits CO_2. The quantity of CO_2 emitted from this process would be listed under process air emissions. Fuel-related emissions are those emissions that result from the combustion of fuels. For example, the combustion of wood by-products in a paper mill produces a fuel-related solid waste, ash. The emissions reported on the data tables in the product summaries are the quantities that reach the environment (air, water, and land) after pollution control measures have been taken.

Atmospheric emissions include substances released to the air that are regulated or classified as pollutants. Emissions are reported as pounds of pollutant per annual tonnage of waste managed. Atmospheric emissions also include CO_2 releases, which are calculated from fuel combustion data or process chemistry. CO_2 emissions are not regulated; however, we are reporting them in this study because of the growing concern about global warming. CO_2 emissions are labeled as being from either fossil or nonfossil fuels.

CO_2 released from the combustion of fossil carbon sources (for example, coal, natural gas, or petroleum) or released during the reaction of chemicals derived from these materials is classified as fossil CO_2. CO_2 released from mineral sources (for example, the calcining of limestone to lime), is also classified as fossil CO_2. CO_2 from sources other than fossil carbon sources (that is, from biomass) is classified as nonfossil carbon dioxide. Nonfossil CO_2 includes CO_2 released from the combustion of plant or animal material or released during the reaction of chemicals derived from these materials. The labeling of the CO_2 releases as either fossil or nonfossil is done to aid in the interpretation of the life cycle inventory data. The source of CO_2 releases is an important issue in the context of natural carbon cycle and global warming.

Waterborne Pollutants

Waterborne wastes are produced from both process activities and fuel-production activities. These are reported as pounds of pollutant per tonnage of waste managed. Similar to air emissions, the waterborne pollutants include substances released to the surface and groundwaters that are regulated or classified as pollutants. The values reported are the average quantity of pollutants still present in the wastewater stream after wastewater treatment and represent discharges into receiving waters.

Air or waterborne emissions that are not regulated or reported to regulatory agencies are not reported in the inventory results presented in the material summaries. Reliable data for any such emissions would be difficult to obtain, except for a site-specific study where additional testing were authorized. Conversely, some air and waterborne emissions data that are regulated and reported may not have been included in the inventory results. The data used represent the best available from existing sources.

Solid Waste

Similar to air and water emissions, solid wastes are produced from process and fuel production activities and are reported as pounds of pollutant per tonnage of waste managed. Process solid wastes include mineral processing wastes (such as red mud from alumina manufacturing); wastewater treatment sludge; solids collected in air pollution control devices; trim or waste materials from manufacturing operations that are not recycled; and packaging materials from material suppliers.

Fuel-related solid wastes are fuel production and combustion residues, such as the ash generated by burning coal or wood.

Life Cycle Inventory Scenarios Analyzed

We generated inventory results for the hypothetical conversion technology growth scenario outlined in Chapter Two, as well as for several alternative management scenarios. The LCI results were generated for the Greater Los Angeles and San Francisco Bay Regions for the conversion technology scenarios when compared to scenarios using existing MSW management practices from 2003 to 2010. The complete set of scenarios analyzed consists of the following:

1. Landfill with no gas collection (worst landfill case).
2. Landfill with gas collection and flaring (average landfill case).

3. Landfill with gas collection and energy recovery (best landfill case).
4. WTE combustion with ferrous recovery and disposal of combustion ash.
5. Organics composting (inorganic wastes are landfilled).
6. Mixed waste recycling (with 35percent separation efficiency at the MRF).
7. Mixed waste recycling (with 55 percent separation efficiency at the MRF).
8. Mixed waste recycling (with 75 percent separation efficiency at the MRF).
9. Conversion technologies system, including acid hydrolysis, gasification and catalytic cracking implemented at their defined capacities:

    2003 (Base Year)

    - Three 500 dry tpd acid hydrolysis facilities in each region (1,500 dry tpd total).
    - Four 500 dry tpd gasification facilities in each region (2,000 dry tpd total).
    - One stand-alone 50 dry tpd catalytic cracking facility in each region.

    Years 2004 to 2010

    - One additional 500 dry tpd gasification plant built in each region in the year 2005.
    - Two additional 500 dry tpd acid hydrolysis plants built in each region in 2007.
    - One additional 500 dry tpd gasification plant built in each region in 2010.

The conversion technologies and alternative scenarios were evaluated consistently on an "apples to apples" basis. We assume each of the nine scenarios manages the same quantity and composition of waste from each region for each year. For example, the same quantity and composition of MSW from the Greater Los Angeles region is sent to the conversion technology scenario, as well as to the other eight alternative scenarios. Therefore, for each region and study year, the results across the nine scenarios can be directly compared.

Note that we considered each management scenario separately and did not attempt to develop optimized scenarios involving the co-location of various combined technologies because this was beyond the scope of the study.

Key assumptions for each scenario are illustrated in Figures 5 through 11. As a general design of the study, conversion technologies were compared to alternative waste management options as desired by the CIWMB. We could have compared the conversion technologies to facilities producing similar products, such as petroleum refineries; however, because the purpose of this study was to evaluate conversion technologies as waste management alternatives, and not as energy or chemical production alternatives, focus was placed on comparing conversion technologies to alternative waste management options.

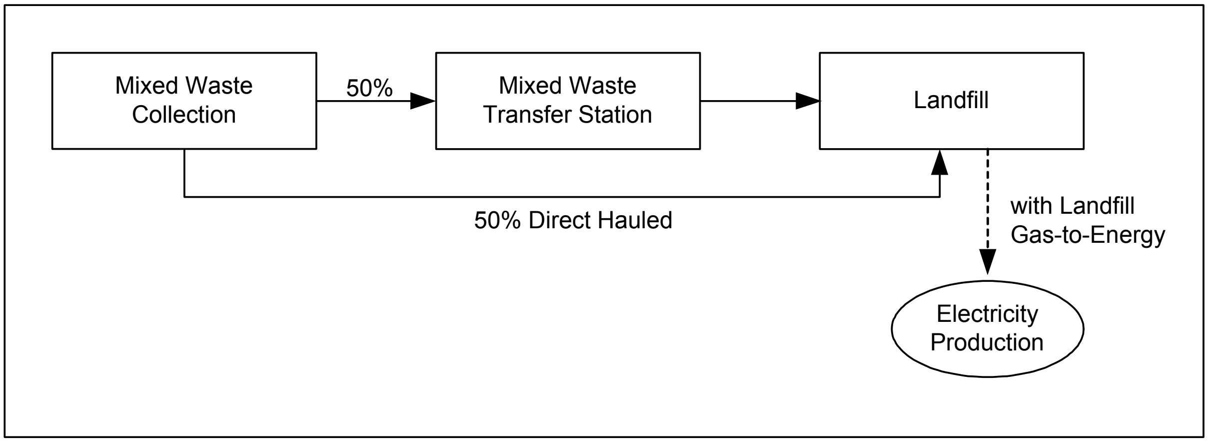

Figure 5. Landfill Disposal Scenario Design

For the landfill scenarios (Scenarios 1-3), we assume that half of the waste is direct hauled to the landfill and half is routed first through a transfer station. The landfill can either vent, flare, or recover landfill gas for electricity production**.**

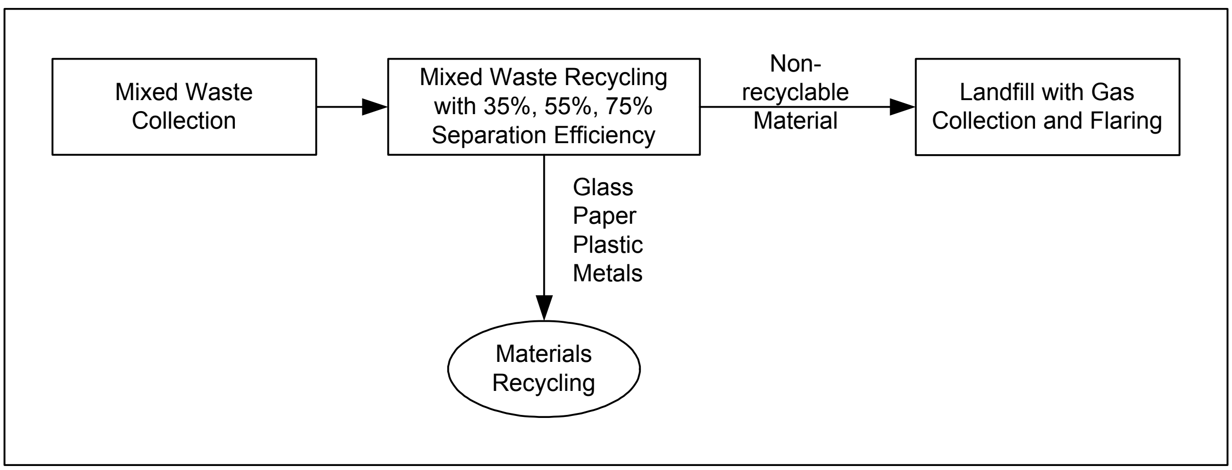

Figure 6. Recycling Scenario Design

For the recycling scenarios (Scenarios 6-8), we assumed various separation efficiencies (35 percent, 55 percent, 75 percent). Separation efficiency refers to the amount of incoming recyclable material that is recovered. The unrecovered recyclable material and residual wastes are assumed to be disposed in a landfill with gas collection and flaring.

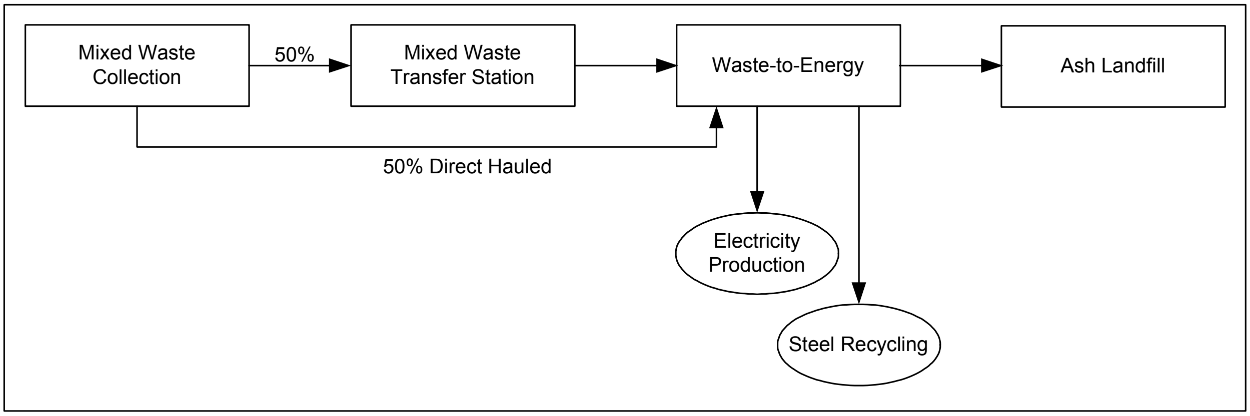

Figure 7. Waste-to-Energy Scenario Design

For the WTE scenario (Scenario 4), we assume, similar to the landfill scenario, that half of the waste is direct hauled to the WTE plant and half is routed first through a transfer station. The WTE plant is assumed to generate electrical energy and recover ferrous metal from the combustion ash. The combustion ash is transported to an ash landfill for disposal.

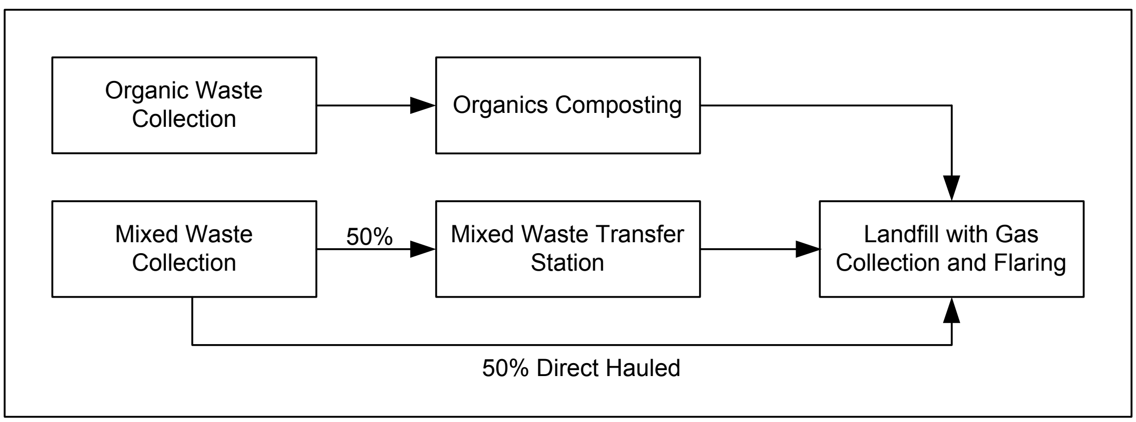

Figure 8. Compost Scenario Design

For the compost scenario (Scenario 5), we assumed that organic materials are collected separately and taken to a compost facility. The residual (inorganic) fraction is disposed of in a landfill with gas collection and flaring. Although compost product can and is used in a variety of applications, we did not include a compost product offset in the scenario. The CIWMB's report *Assessment of California's Compost and Mulch-Producing Infrastructure* (2001) states that approximately 85 percent of the compost product produced in California is used for agricultural and horticultural applications; however, no discernable offset of another product could be established.

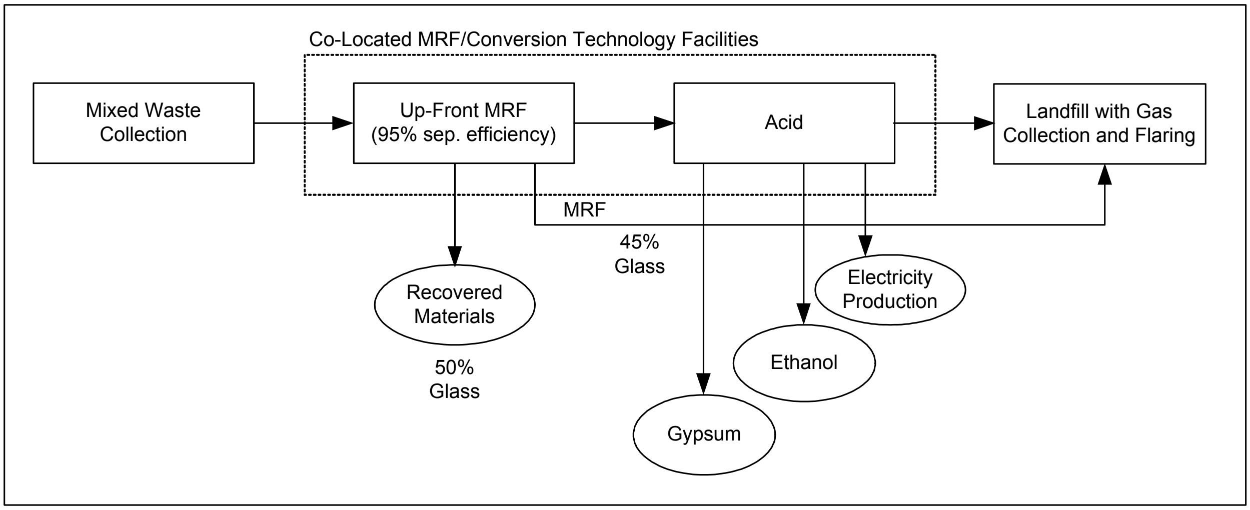

Figure 9. Acid Hydrolysis Scenario Design
(Included as part of the conversion technologies scenario, Scenario 9.)
For the acid hydrolysis scenario, we assume that waste is collected as mixed waste and taken to a co-located MRF and hydrolysis facility. The unwanted materials are removed and recycled or landfilled. The main products of hydrolysis are assumed to be ethanol and gypsum.

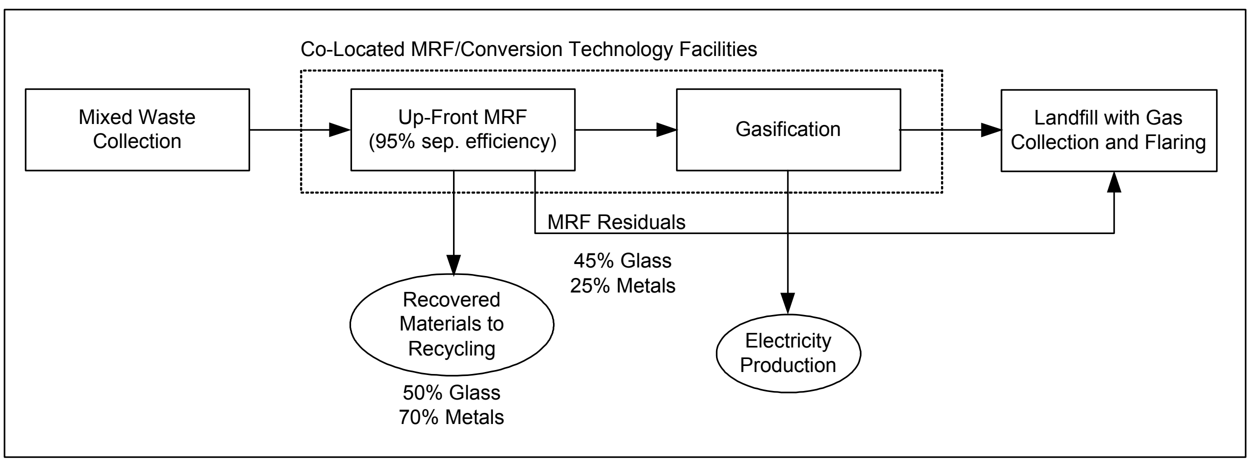

Figure 10. Gasification Scenario Design
(Included as part of the conversion technologies scenario, Scenario 9.)
For the gasification scenario, we assume that waste is collected as mixed waste and taken to a co-located MRF and gasification facility. The unwanted materials are removed and recycled or landfilled. The main product of gasification is assumed to be electrical energy.

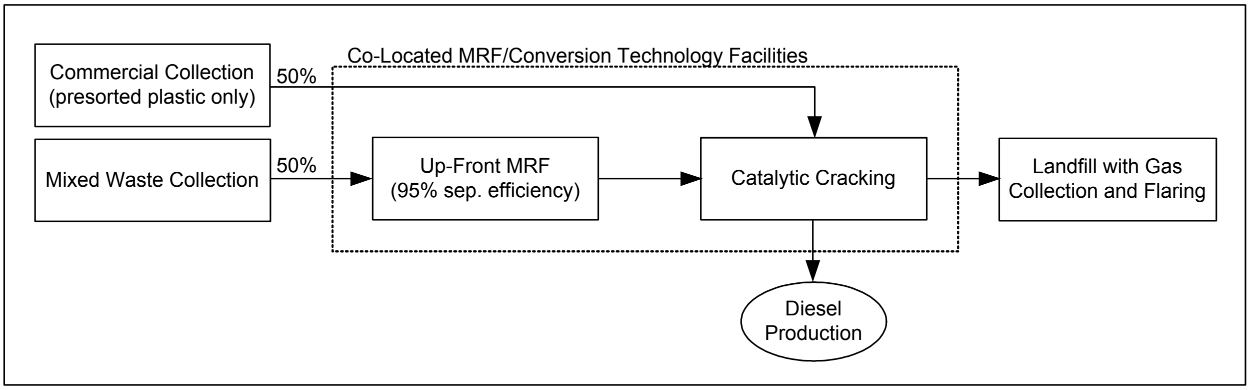

Figure 11. Catalytic Cracking Scenario Design
(Included as part of the conversion technologies scenario, Scenario 9.)

For the catalytic cracking scenario, we assume that half of the catalytic cracking feedstock is collected from the commercial sector as presorted plastic. The other half of the feedstock is collected as mixed waste and taken to a co-located MRF and catalytic cracking facility. The unwanted materials are removed and landfilled. The main product of catalytic cracking is assumed to be low sulfur diesel fuel.

Chapter 4 Life Cycle Study Results and Key Findings

In this chapter, we summarize the results and highlight what we feel to be the key findings from the life cycle (environmental) portion of the study. Although we used the best available information to characterize the life cycle environmental burdens from the hypothetical conversion technology scenario, the conversion technologies do not yet exist in California. Thus, we made a number of assumptions about their design and operating characteristics. The findings from this study need to be taken in context and considered as general directional conclusions, rather than absolute conclusions.

Additional research that we feel is needed to further characterize the life cycle impacts from conversion technologies are listed in Chapter 7.

Life Cycle Inventory Results and Key Findings

The detailed results for each of the model years in each of the Los Angeles and San Francisco regions are presented in Tables 7 through 14 (a complete breakdown of results is included in Appendix C). Each table contains the nine defined waste management strategies for a specified model year and region. Results are expressed as either a positive or a negative value. A positive value represents a net life cycle burden. A negative value represents a net life cycle savings or avoidance for that stressor (defined as a resource, emission, energy consumption, or waste). In effect, negative values indicate that energy and materials offsets from any particular scenario are less than those associated with the processes included in the scenario.

The air and waterborne emissions data reported in the life cycle inventory tables are aggregated across the life cycle of the product being studied. They represent a mixture of measured data from actual facilities, calculated data from actual facilities, and estimates based on regulatory emissions standards. Actual environmental impacts from these aggregated emissions could be extremely difficult to estimate; however, the results of this study should be within the range of emissions from actual systems.

Table 7. Summary LCI Results for 2003, Greater Los Angeles Region

Parameter	Units	Landfill - Venting	Landfill - Flaring	Landfill - ER	WTE	Compost*	Recycling 35%	Recycling 55%	Recycling 75%	CT
Energy Consumption	MBTU	1,114,328	1,114,328	310,832	-5,750,023	989,839	-1,028,240	-2,179,300	-3,327,631	-11,625,729
Air Emissions										
Total Particulate Matter	lb	91,517	170,014	22,606	-471,745	51,478	-181,110	-393,328	-604,520	-620,990
Nitrogen Oxides	lb	1,079,104	1,270,439	1,261,354	393,792	1,423,125	579,018	184,104	-207,345	-785,468
Sulfur Oxides	lb	150,421	199,482	-1,924,505	-3,640,319	159,610	-726,425	-1,406,587	-2,079,418	-2,761,819
Carbon Monoxide	lb	746,492	4,278,821	2,793,265	550,658	351,714	3,148,672	2,315,659	1,483,217	69,618
Carbon Dioxide Biomass	lb	5,614,012,219	5,864,917,061	5,893,603,127	1,630,565,029	519,865,553	5,749,696,454	5,674,716,517	5,599,747,823	2,547,441,575
Carbon Dioxide Fossil	lb	40,941,936	40,941,924	-224,232,718	-245,114,881	43,172,443	-56,180,202	-119,431,720	-181,768,233	-454,435,387
Greenhouse Equivalents	MTCE	3,940,475	1,058,821	1,029,705	-36,986	5,977	823,563	794,708	765,984	-45,210
Hydrocarbons (non CH4)	lb	218,272	218,272	6,146	-369,662	168,900	-660,772	-876,926	-1,092,348	-401,409
Lead	lb	1	1	-9	55	1	-44	-71	-97	206,184
Ammonia	lb	44	44	-1,173	-2,526	5,699	-3,209	-5,217	-7,221	660,369
Methane	lb	1,374,089,423	367,797,442	370,257,346	-1,243,742	31,396	290,268,554	283,204,246	276,142,019	-1,147,193
Hydrochloric Acid	lb	6,826	53,924	33,696	283,338	196	44,863	37,069	29,337	-50,093
Total Solid Waste	lb	3,935,693	3,935,693	-42,040,594	-99,710,480	786,539	-9,295,582	-23,701,526	-37,948,870	-130,540,843
Water Emissions										
Dissolved Solids	lb	134,066	134,066	-994,735	-2,244,039	613,821	-158,031	-457,816	-753,707	-2,726,653
Suspended Solids	lb	5,477	5,477	-166,911	-361,780	233,546	104,789	147,230	190,265	-466,221
BOD	lb	692,336	692,336	686,899	-1,872	147,303	796,619	856,819	917,022	8,669
COD	lb	1,928,133	1,928,133	1,900,299	-13,641	1,470,824	1,725,787	1,606,710	1,487,688	-29,262
Oil	lb	230,724	230,724	210,178	-5,786	114,864	216,764	208,588	200,480	-33,321
Sulfuric Acid	lb	50	50	-2,160	-4,518	40	-396	-871	-1,338	-5,222
Iron	lb	221	221	-12,994	-27,127	6,864	8,458	11,861	15,308	-21,743
Ammonia	lb	22,121	22,121	21,852	-1,325	48,298	18,918	17,232	15,547	471,549
Copper	lb	0	0	0	0	40	0	0	0	171
Cadmium	lb	5	5	-46	-102	107	-9	-24	-38	-119
Arsenic	lb	0	0	0	0	0	0	0	0	25
Mercury	lb	0	0	0	0	0	0	0	0	1
Phosphate	lb	167	167	-938	-2,198	17,810	102	-28	-155	-2,605
Selenium	lb	0	0	0	0	0	0	0	0	0
Chromium	lb	6	6	-45	-102	19	-9	-23	-38	-60
Lead	lb	0	0	0	0	183	0	0	0	223
Zinc	lb	2	2	-15	-34	137	106	163	220	432

* NOTE: No offset was assumed for the compost product. Including an offset would likely drop the energy consumption to near zero and may even result in a net energy savings.

Table 8. Summary LCI Results for 2005, Greater Los Angeles Region

Parameter	Units	Landfill - Venting	Landfill - Flaring	Landfill - ER	WTE	Compost*	Recycling 35%	Recycling 55%	Recycling 75%	CT
Energy Consumption	MBTU	1,256,463	1,256,463	349,760	-6,401,189	1,139,248	-1,057,821	-2,322,135	-3,583,426	-12,900,635
Air Emissions										
Total Particulate Matter	lb	104,565	194,170	25,519	-524,746	62,243	-183,414	-415,239	-645,927	-782,128
Nitrogen Oxides	lb	1,217,828	1,436,241	1,425,563	452,683	1,638,571	700,684	264,792	-167,263	-956,919
Sulfur Oxides	lb	169,512	225,515	-2,177,934	-4,063,830	188,498	-764,311	-1,508,619	-2,244,814	-3,755,533
Carbon Monoxide	lb	827,439	4,859,689	3,160,364	623,943	425,294	3,625,531	2,710,844	1,796,789	-30,488
Carbon Dioxide Biomass	lb	6,386,351,020	6,672,765,653	6,669,079,112	1,838,543,926	589,685,497	6,544,881,280	6,462,225,621	6,379,582,407	2,965,728,674
Carbon Dioxide Fossil	lb	46,204,675	46,204,663	-253,802,660	-277,749,675	52,076,284	-53,846,615	-123,047,468	-191,235,554	-308,929,805
Greenhouse Equivalents	MTCE	4,497,535	1,208,049	1,165,184	-41,855	7,169	942,142	910,403	878,808	-28,553
Hydrocarbons (non CH4)	lb	246,483	246,483	6,589	-410,834	202,141	-677,650	-924,577	-1,170,695	-486,972
Lead	lb	1	1	-11	62	1	-48	-78	-107	257,730
Ammonia	lb	49	49	-1,328	-2,823	6,466	-3,528	-5,737	-7,942	825,602
Methane	lb	1,568,367,381	419,657,986	418,975,515	-1,389,923	23,661	331,566,205	323,777,796	315,991,690	-1,405,713
Hydrochloric Acid	lb	7,501	61,264	38,130	318,427	223	51,935	43,537	35,209	-59,184
Total Solid Waste	lb	4,427,995	4,427,995	-47,573,062	-111,365,421	907,027	-9,563,096	-24,977,100	-40,215,558	-154,022,148
Water Emissions										
Dissolved Solids	lb	151,358	151,358	-1,125,826	-2,506,918	699,744	-159,038	-484,450	-805,551	-3,264,952
Suspended Solids	lb	6,173	6,173	-188,879	-404,290	264,758	117,677	164,921	212,823	-550,467
BOD	lb	778,526	778,526	777,279	-2,090	166,900	893,356	959,685	1,026,017	8,178
COD	lb	2,168,179	2,168,179	2,150,333	-15,188	1,666,779	1,944,160	1,812,809	1,681,518	-34,971
Oil	lb	259,752	259,752	237,380	-6,371	129,699	244,897	235,939	227,056	-38,032
Sulfuric Acid	lb	56	56	-2,444	-5,049	46	-444	-977	-1,501	-6,285
Iron	lb	249	249	-14,704	-30,316	7,781	9,432	13,210	17,039	-25,475
Ammonia	lb	24,875	24,875	24,727	-1,465	54,734	21,362	19,500	17,639	471,405
Copper	lb	0	0	0	0	45	0	0	0	215
Cadmium	lb	6	6	-52	-114	121	-9	-25	-41	-142
Arsenic	lb	0	0	0	0	0	0	0	0	31
Mercury	lb	0	0	0	0	0	0	0	0	1
Phosphate	lb	188	188	-1,062	-2,457	20,183	127	-15	-153	-3,132
Selenium	lb	0	0	0	0	0	0	0	0	0
Chromium	lb	7	7	-51	-114	22	-9	-25	-41	-64
Lead	lb	0	0	0	0	208	0	0	0	280
Zinc	lb	3	3	-17	-38	156	117	180	243	548

Table 9. Summary LCI Results for 2007, Greater Los Angeles Region

Parameter	Units	Landfill - Venting	Landfill - Flaring	Landfill - ER	WTE	Compost*	Recycling 35%	Recycling 55%	Recycling 75%	CT
Energy Consumption	MBTU	1,592,938	1,592,938	440,493	-8,053,525	1,448,012	-1,259,296	-2,866,272	-4,469,407	-16,975,250
Air Emissions										
Total Particulate Matter	lb	132,778	246,669	32,309	-659,277	79,113	-222,631	-517,286	-810,497	-736,445
Nitrogen Oxides	lb	1,544,268	1,821,877	1,808,304	571,806	2,082,664	943,692	389,663	-159,491	-960,010
Sulfur Oxides	lb	215,033	286,215	-2,768,635	-5,091,232	239,586	-944,080	-1,890,116	-2,825,839	-2,947,310
Carbon Monoxide	lb	1,050,797	6,175,895	4,016,007	778,366	540,559	4,596,445	3,433,853	2,272,063	297,277
Carbon Dioxide Biomass	lb	8,117,224,308	8,481,265,033	8,476,579,339	2,336,974,177	749,506,042	8,318,712,221	8,213,654,646	8,108,612,889	3,463,473,613
Carbon Dioxide Fossil	lb	58,592,337	58,592,324	-322,725,080	-369,938,411	66,190,266	-56,850,848	-144,806,997	-231,475,893	-455,640,277
Greenhouse Equivalents	MTCE	5,716,469	1,535,444	1,480,962	-55,434	9,112	1,199,062	1,158,720	1,118,562	-36,933
Hydrocarbons (non CH4)	lb	312,533	312,533	7,622	-515,724	256,927	-708,295	-1,022,146	-1,334,968	-489,901
Lead	lb	1	1	-13	79	1	-62	-99	-136	257,729
Ammonia	lb	62	62	-1,687	-3,539	8,218	-4,496	-7,304	-10,107	825,239
Methane	lb	1,993,437,198	533,396,570	532,529,131	-1,741,765	30,066	421,427,226	411,527,948	401,631,597	-1,442,713
Hydrochloric Acid	lb	9,533	77,868	48,463	399,788	284	66,359	55,686	45,100	-67,169
Total Solid Waste	lb	5,626,457	5,626,457	-60,468,289	-139,650,674	1,152,853	-13,334,538	-32,926,152	-52,294,643	-175,652,193
Water Emissions										
Dissolved Solids	lb	191,959	191,959	-1,431,375	-3,140,486	889,393	-210,946	-624,554	-1,032,681	-3,623,506
Suspended Solids	lb	7,835	7,835	-240,082	-506,735	336,515	150,568	210,616	271,501	-633,300
BOD	lb	989,525	989,525	987,941	-2,614	212,134	1,135,832	1,220,137	1,304,447	15,319
COD	lb	2,755,800	2,755,800	2,733,117	-18,684	2,118,521	2,470,240	2,303,289	2,136,415	-37,859
Oil	lb	329,219	329,219	300,784	-7,322	164,851	311,225	299,838	288,548	-47,583
Sulfuric Acid	lb	71	71	-3,107	-6,327	59	-569	-1,246	-1,913	-6,912
Iron	lb	316	316	-18,689	-37,986	9,890	11,962	16,764	21,630	-29,856
Ammonia	lb	31,617	31,617	31,428	-1,857	69,568	27,227	24,861	22,495	786,705
Copper	lb	0	0	0	0	57	0	0	0	213
Cadmium	lb	7	7	-66	-143	154	-13	-33	-53	-157
Arsenic	lb	1	1	1	0	0	1	1	1	31
Mercury	lb	0	0	0	0	0	0	0	0	1
Phosphate	lb	239	239	-1,350	-3,078	25,653	167	-14	-189	-3,458
Selenium	lb	0	0	0	1	0	0	0	0	0
Chromium	lb	9	9	-65	-143	28	-12	-32	-53	-89
Lead	lb	0	0	0	0	264	0	0	0	275
Zinc	lb	4	4	-22	-48	198	149	228	308	528

Table 10. Summary LCI Results for 2010, Greater Los Angeles Region

Parameter	Units	Landfill - Venting	Landfill - Flaring	Landfill - ER	WTE	Compost*	Recycling 35%	Recycling 55%	Recycling 75%	CT
Energy Consumption	MBTU	1,740,291	1,740,291	480,228	-8,777,136	1,583,230	-1,347,528	-3,104,567	-4,857,407	-18,304,980
Air Emissions										
Total Particulate Matter	lb	145,133	269,660	35,282	-718,193	86,501	-239,805	-561,976	-882,568	-906,909
Nitrogen Oxides	lb	1,687,226	1,990,759	1,975,919	623,974	2,277,147	1,050,114	444,347	-156,088	-1,153,757
Sulfur Oxides	lb	234,968	312,797	-3,027,321	-5,541,164	261,959	-1,022,806	-2,057,185	-3,080,289	-3,942,521
Carbon Monoxide	lb	1,148,613	6,752,304	4,390,721	845,993	591,037	5,021,639	3,750,481	2,480,202	190,336
Carbon Dioxide Biomass	lb	8,875,229,069	9,273,264,741	9,268,141,488	2,555,253,010	819,496,570	9,095,529,512	8,980,661,422	8,865,810,627	3,907,289,535
Carbon Dioxide Fossil	lb	64,017,283	64,017,270	-352,908,418	-410,310,784	72,371,230	-58,166,498	-154,336,191	-249,098,424	-476,734,241
Greenhouse Equivalents	MTCE	6,250,280	1,678,820	1,619,251	-61,380	9,963	1,311,575	1,267,466	1,223,558	-40,562
Hydrocarbons (non CH4)	lb	341,458	341,458	8,074	-561,659	280,919	-721,715	-1,064,874	-1,406,908	-575,994
Lead	lb	1	1	-15	87	2	-67	-108	-149	309,276
Ammonia	lb	68	68	-1,845	-3,852	8,986	-4,919	-7,990	-11,054	990,466
Methane	lb	2,179,588,863	583,206,333	582,257,891	-1,895,827	32,871	460,780,241	449,956,545	439,136,051	-1,705,752
Hydrochloric Acid	lb	10,423	85,139	52,989	435,419	310	72,676	61,006	49,431	-76,639
Total Solid Waste	lb	6,151,303	6,151,302	-66,115,521	-152,037,684	1,260,509	-14,986,173	-36,407,296	-57,584,461	-200,042,695
Water Emissions										
Dissolved Solids	lb	209,740	209,740	-1,565,185	-3,417,945	972,446	-233,678	-685,909	-1,132,149	-4,171,271
Suspended Solids	lb	8,562	8,562	-262,505	-551,599	367,939	164,972	230,627	297,198	-718,815
BOD	lb	1,081,929	1,081,929	1,080,196	-2,843	231,943	1,242,019	1,334,197	1,426,381	14,816
COD	lb	3,013,138	3,013,138	2,988,337	-20,214	2,316,353	2,700,627	2,518,086	2,335,628	-43,776
Oil	lb	359,641	359,641	328,551	-7,738	180,246	340,272	327,822	315,478	-52,267
Sulfuric Acid	lb	78	78	-3,397	-6,886	64	-623	-1,364	-2,093	-7,985
Iron	lb	345	345	-20,434	-41,345	10,814	13,069	18,320	23,641	-33,640
Ammonia	lb	34,569	34,569	34,363	-2,029	76,065	29,796	27,208	24,622	786,537
Copper	lb	0	0	0	0	63	0	0	0	257
Cadmium	lb	8	8	-72	-155	168	-14	-36	-58	-181
Arsenic	lb	1	1	1	0	0	1	1	1	37
Mercury	lb	0	0	0	0	0	0	0	0	1
Phosphate	lb	261	261	-1,476	-3,349	28,049	184	-13	-205	-3,989
Selenium	lb	0	0	0	1	0	0	0	0	0
Chromium	lb	10	10	-71	-155	31	-13	-36	-58	-94
Lead	lb	0	0	0	0	289	0	0	0	333
Zinc	lb	4	4	-24	-52	216	162	250	337	644

Table 11. Summary LCI Results for 2003, San Francisco Bay Region

Parameter	Units	Landfill - Venting	Landfill - Flaring	Landfill - ER	WTE	Compost*	Recycling 35%	Recycling 55%	Recycling 75%	CT
Energy Consumption	MBTU	1,138,198	1,138,198	337,173	-5,904,822	1,030,916	-1,061,506	-2,247,614	-3,430,921	-11,676,983
Air Emissions										
Total Particulate Matter	lb	92,552	171,713	22,719	-483,380	55,792	-189,018	-407,401	-624,730	-624,943
Nitrogen Oxides	lb	1,101,638	1,294,595	1,285,161	401,485	1,474,820	590,466	185,884	-215,142	-736,252
Sulfur Oxides	lb	153,448	202,924	-1,920,395	-3,710,457	169,570	-743,885	-1,440,341	-2,129,274	-2,753,091
Carbon Monoxide	lb	763,781	4,326,059	2,824,796	554,692	381,774	3,162,991	2,309,273	1,456,142	54,377
Carbon Dioxide Biomass	lb	5,669,614,953	5,922,646,983	5,919,390,121	1,661,021,637	525,460,292	5,804,538,890	5,727,827,811	5,651,128,270	2,555,792,096
Carbon Dioxide Fossil	lb	41,785,977	41,785,965	-223,254,480	-249,696,536	46,860,093	-56,971,703	-121,834,911	-185,759,166	-442,082,311
Greenhouse Equivalents	MTCE	3,974,150	1,068,065	1,030,197	-37,680	6,451	830,208	800,678	771,283	-45,952
Hydrocarbons (non CH4)	lb	222,820	222,820	10,887	-378,988	182,423	-667,171	-890,373	-1,112,825	-398,966
Lead	lb	1	1	-9	57	1	-45	-72	-99	206,185
Ammonia	lb	45	45	-1,172	-2,574	5,756	-3,284	-5,338	-7,387	660,385
Methane	lb	1,385,808,674	370,985,278	370,382,351	-1,267,848	21,314	292,626,902	285,403,632	278,182,499	-1,141,598
Hydrochloric Acid	lb	6,990	54,487	34,049	288,665	200	45,220	37,259	29,361	-49,987
Total Solid Waste	lb	3,996,321	3,996,320	-41,943,836	-101,743,119	815,613	-9,656,127	-24,393,643	-38,968,409	-130,384,581
Water Emissions										
Dissolved Solids	lb	136,778	136,778	-991,545	-2,286,827	624,747	-162,860	-469,357	-771,856	-2,712,826
Suspended Solids	lb	5,577	5,577	-166,741	-368,780	235,624	106,690	149,817	193,555	-464,658
BOD	lb	702,491	702,491	701,390	-1,907	148,508	808,929	870,357	931,788	8,685
COD	lb	1,956,429	1,956,429	1,940,663	-13,711	1,483,077	1,748,818	1,626,697	1,504,632	-29,064
Oil	lb	235,901	235,901	216,137	-5,525	118,650	221,636	213,242	204,918	-32,653
Sulfuric Acid	lb	51	51	-2,158	-4,604	41	-418	-909	-1,393	-5,193
Iron	lb	224	224	-12,985	-27,643	6,925	8,647	12,129	15,658	-21,570
Ammonia	lb	22,446	22,446	22,315	-1,378	48,700	19,168	17,439	15,710	471,512
Copper	lb	0	0	0	0	40	0	0	0	171
Cadmium	lb	5	5	-46	-104	108	-9	-24	-39	-118
Arsenic	lb	0	0	0	0	0	0	0	0	25
Mercury	lb	0	0	0	0	0	0	0	0	1
Phosphate	lb	170	170	-934	-2,239	17,958	104	-30	-159	-2,589
Selenium	lb	0	0	0	0	0	0	0	0	0
Chromium	lb	6	6	-45	-104	20	-9	-24	-39	-59
Lead	lb	0	0	0	0	185	0	0	0	223
Zinc	lb	3	3	-15	-35	139	108	167	225	432

Table 12. Summary LCI Results for 2005, San Francisco Bay Region

Parameter	Units	Landfill - Venting	Landfill - Flaring	Landfill - ER	WTE	Compost*	Recycling 35%	Recycling 55%	Recycling 75%	CT
Energy Consumption	MBTU	1,289,688	1,289,688	446,515	-6,272,629	1,185,670	-1,093,750	-2,400,660	-3,704,413	-12,878,039
Air Emissions										
Total Particulate Matter	lb	106,753	190,080	33,246	-515,356	61,672	-213,410	-460,645	-706,692	-794,727
Nitrogen Oxides	lb	1,246,892	1,450,001	1,440,071	469,291	1,659,244	676,718	216,817	-239,078	-931,367
Sulfur Oxides	lb	171,551	223,631	-2,011,415	-3,994,203	190,358	-838,440	-1,629,290	-2,411,665	-3,757,591
Carbon Monoxide	lb	824,640	4,574,359	2,994,102	607,643	424,715	3,243,832	2,282,265	1,321,358	-28,542
Carbon Dioxide Biomass	lb	5,967,153,262	6,233,499,494	6,230,071,260	1,743,853,861	564,262,890	6,099,609,662	6,013,370,605	5,927,144,549	3,000,765,506
Carbon Dioxide Fossil	lb	47,175,865	47,175,853	-231,810,660	-240,185,960	52,665,558	-58,828,551	-132,288,533	-204,690,537	-494,745,617
Greenhouse Equivalents	MTCE	4,183,683	1,124,683	1,084,822	-36,658	7,251	871,932	838,929	806,077	-53,907
Hydrocarbons (non CH4)	lb	252,660	252,660	29,576	-394,024	207,540	-696,325	-958,482	-1,219,793	-479,647
Lead	lb	1	1	-10	67	1	-51	-81	-112	257,730
Ammonia	lb	49	49	-1,231	-2,772	6,177	-3,694	-6,001	-8,304	825,604
Methane	lb	1,458,722,147	390,500,123	389,865,471	-1,363,843	24,050	307,285,633	299,258,883	291,234,539	-1,412,311
Hydrochloric Acid	lb	7,355	57,351	35,838	307,845	223	46,593	37,459	28,396	-59,317
Total Solid Waste	lb	4,249,058	4,249,057	-44,108,407	-109,359,037	914,120	-11,834,755	-28,557,780	-45,097,424	-40,241,302
Water Emissions										
Dissolved Solids	lb	154,141	154,140	-1,033,554	-2,456,133	680,063	-179,954	-521,905	-859,351	-3,267,352
Suspended Solids	lb	6,140	6,140	-175,245	-397,041	253,004	115,238	160,681	206,813	-552,505
BOD	lb	740,058	740,058	738,899	-2,028	159,344	854,908	921,123	987,343	8,184
COD	lb	2,061,240	2,061,240	2,044,644	-12,065	1,591,162	1,819,353	1,677,411	1,535,533	-35,007
Oil	lb	268,064	268,064	247,260	-702	142,398	252,635	243,293	234,030	-36,718
Sulfuric Acid	lb	55	55	-2,270	-4,956	47	-574	-1,187	-1,791	-6,283
Iron	lb	242	242	-13,662	-29,759	7,434	9,705	13,611	17,570	-25,459
Ammonia	lb	23,650	23,650	23,512	-1,452	52,245	20,054	18,141	16,228	471,407
Copper	lb	0	0	0	0	43	0	0	0	215
Cadmium	lb	6	6	-48	-112	116	-10	-27	-44	-142
Arsenic	lb	0	0	0	0	0	0	0	0	31
Mercury	lb	0	0	0	0	0	0	0	0	1
Phosphate	lb	180	180	-982	-2,411	19,264	101	-53	-204	-3,131
Selenium	lb	0	0	0	0	0	0	0	0	0
Chromium	lb	7	7	-47	-112	21	-10	-27	-43	-65
Lead	lb	0	0	0	0	198	0	0	0	280
Zinc	lb	3	3	-16	-38	149	122	188	254	548

Table 13. Summary LCI Results for 2007, San Francisco Bay Region

Parameter	Units	Landfill - Venting	Landfill - Flaring	Landfill - ER	WTE	Compost*	Recycling 35%	Recycling 55%	Recycling 75%	CT
Energy Consumption	MBTU	1,634,365	1,634,365	563,200	-7,886,364	1,506,270	-1,304,471	-2,964,766	-4,621,050	-16,944,381
Air Emissions										
Total Particulate Matter	lb	135,492	241,351	42,109	-647,036	78,348	-260,646	-574,732	-887,310	-752,253
Nitrogen Oxides	lb	1,580,432	1,838,461	1,825,846	592,628	2,107,896	912,682	328,424	-250,742	-927,697
Sulfur Oxides	lb	217,518	283,680	-2,555,716	-5,000,391	241,830	-1,037,835	-2,042,529	-3,036,456	-2,949,815
Carbon Monoxide	lb	1,046,722	5,810,355	3,802,800	757,298	539,556	4,109,279	2,887,707	1,666,973	300,038
Carbon Dioxide Biomass	lb	7,580,653,750	7,919,019,216	7,914,663,998	2,215,520,838	716,837,777	7,748,917,664	7,639,359,818	7,529,818,489	3,498,514,621
Carbon Dioxide Fossil	lb	59,797,352	59,797,339	-294,626,306	-322,003,377	66,906,074	-63,172,902	-156,496,245	-248,475,536	-641,353,628
Greenhouse Equivalents	MTCE	5,314,920	1,428,776	1,378,137	-48,800	9,211	1,109,270	1,067,343	1,025,608	-62,279
Hydrocarbons (non CH4)	lb	320,227	320,227	36,821	-494,126	263,658	-731,948	-1,064,992	-1,396,961	-480,116
Lead	lb	1	1	-12	86	1	-64	-103	-142	257,729
Ammonia	lb	63	63	-1,564	-3,472	7,848	-4,704	-7,636	-10,561	825,242
Methane	lb	1,853,156,252	496,090,151	495,283,891	-1,707,878	30,546	390,372,400	380,175,241	369,981,138	-1,451,090
Hydrochloric Acid	lb	9,344	72,859	45,528	386,156	283	59,539	47,935	36,422	-67,335
Total Solid Waste	lb	5,396,351	5,396,351	-56,036,830	-137,036,048	1,161,293	-16,211,680	-37,456,562	-58,468,477	-176,001,249
Water Emissions										
Dissolved Solids	lb	195,400	195,400	-1,313,443	-3,074,496	863,949	-237,397	-671,810	-1,100,501	-3,626,605
Suspended Solids	lb	7,789	7,789	-222,642	-497,288	321,416	147,392	205,124	263,729	-635,883
BOD	lb	940,166	940,166	938,693	-2,535	202,430	1,086,423	1,170,543	1,254,669	15,328
COD	lb	2,618,579	2,618,579	2,597,496	-14,709	2,021,407	2,310,462	2,130,140	1,949,898	-37,906
Oil	lb	339,617	339,617	313,188	-117	180,902	320,901	309,033	297,265	-45,559
Sulfuric Acid	lb	70	70	-2,884	-6,205	59	-735	-1,513	-2,280	-6,910
Iron	lb	307	307	-17,357	-37,261	9,444	12,303	17,265	22,294	-29,836
Ammonia	lb	30,045	30,045	29,869	-1,840	66,371	25,552	23,122	20,692	786,710
Copper	lb	0	0	0	0	55	0	0	0	213
Cadmium	lb	8	8	-61	-140	147	-14	-35	-56	-157
Arsenic	lb	1	1	1	0	0	1	1	0	31
Mercury	lb	0	0	0	0	0	0	0	0	1
Phosphate	lb	228	228	-1,248	-3,018	24,474	134	-62	-254	-3,458
Selenium	lb	0	0	0	0	0	0	0	0	0
Chromium	lb	9	9	-59	-140	27	-13	-35	-56	-89
Lead	lb	0	0	0	0	252	0	0	0	275
Zinc	lb	4	4	-20	-47	189	155	238	322	528

Table 14. Summary LCI Results for 2010, San Francisco Bay Region

Parameter	Units	Landfill - Venting	Landfill - Flaring	Landfill - ER	WTE	Compost*	Recycling 35%	Recycling 55%	Recycling 75%	CT
Energy Consumption	MBTU	1,785,903	1,785,903	614,501	-8,595,844	1,647,222	-1,397,116	-3,212,777	-5,024,053	-18,271,745
Air Emissions										
Total Particulate Matter	lb	148,128	263,892	46,006	-704,929	85,680	-281,414	-624,891	-966,720	-924,264
Nitrogen Oxides	lb	1,727,074	2,009,249	1,995,453	646,855	2,305,147	1,016,424	377,493	-255,871	-1,118,255
Sulfur Oxides	lb	237,728	310,080	-2,795,020	-5,442,763	264,460	-1,125,500	-2,224,211	-3,311,147	-3,945,281
Carbon Monoxide	lb	1,144,361	6,353,764	4,158,347	823,097	590,046	4,489,776	3,153,891	1,818,925	193,301
Carbon Dioxide Biomass	lb	8,290,035,430	8,660,064,428	8,655,301,658	2,422,893,789	783,917,911	8,474,042,254	8,354,232,214	8,234,440,235	3,949,336,699
Carbon Dioxide Fossil	lb	65,346,428	65,346,415	-322,243,454	-357,974,510	73,166,971	-65,082,913	-167,139,258	-267,725,779	-699,632,401
Greenhouse Equivalents	MTCE	5,812,272	1,562,471	1,507,093	-54,138	10,073	1,213,617	1,167,766	1,122,126	-70,980
Hydrocarbons (non CH4)	lb	349,933	349,933	40,007	-538,135	288,331	-747,610	-1,111,819	-1,474,853	-565,452
Lead	lb	1	1	-14	94	2	-70	-113	-155	309,275
Ammonia	lb	69	69	-1,710	-3,780	8,582	-5,148	-8,354	-11,554	990,469
Methane	lb	2,026,570,719	542,513,212	541,631,504	-1,858,937	33,402	426,901,816	415,750,428	404,602,383	-1,714,912
Hydrochloric Acid	lb	10,218	79,677	49,789	420,586	310	65,231	52,541	39,951	-76,822
Total Solid Waste	lb	5,900,763	5,900,763	-61,281,206	-149,204,287	1,269,964	-18,136,012	-41,368,946	-64,347,111	-200,426,380
Water Emissions										
Dissolved Solids	lb	213,540	213,540	-1,436,498	-3,346,361	944,796	-262,652	-737,716	-1,206,523	-4,174,627
Suspended Solids	lb	8,514	8,514	-243,480	-541,361	351,493	161,529	224,663	288,752	-721,643
BOD	lb	1,028,144	1,028,144	1,026,533	-2,757	221,373	1,188,210	1,280,202	1,372,199	14,826
COD	lb	2,863,616	2,863,616	2,840,560	-15,870	2,210,566	2,526,380	2,329,184	2,132,075	-43,827
Oil	lb	371,076	371,076	342,173	140	197,830	350,915	337,936	325,067	-50,075
Sulfuric Acid	lb	77	77	-3,153	-6,754	65	-805	-1,656	-2,495	-7,982
Iron	lb	336	336	-18,981	-40,559	10,328	13,445	18,872	24,371	-33,618
Ammonia	lb	32,856	32,856	32,664	-2,011	72,582	27,969	25,312	22,654	786,542
Copper	lb	0	0	0	0	60	0	0	0	257
Cadmium	lb	8	8	-67	-152	161	-15	-39	-61	-181
Arsenic	lb	1	1	1	0	0	1	1	1	37
Mercury	lb	0	0	0	0	0	0	0	0	1
Phosphate	lb	250	250	-1,365	-3,284	26,764	149	-66	-275	-3,988
Selenium	lb	0	0	0	0	0	0	0	0	0
Chromium	lb	10	10	-65	-152	30	-15	-38	-61	-94
Lead	lb	0	0	0	0	276	0	0	0	333
Zinc	lb	4	4	-22	-51	207	169	261	352	644

Analysis of Results for Selected Parameters

The results for selected life cycle parameters for the hypothetical conversion technology scenarios are shown relative to comparable alternative management scenarios in Figures 12 through 19. These parameters were identified by the CIWMB as being most important to the CIWMB and include net annual energy consumption, sulfur oxides (SO_x) emissions, NO_x emissions, and carbon equivalents. In addition, dioxin/furans, hazardous air pollutants (HAPs), and toxics were also identified as being a priority in considering the environmental impact of the conversion technology systems, although data characterizing these parameters was limited. Data for additional air and water pollutants are included in the detailed results in Appendix C.

Net Energy Consumption

Energy is consumed by all waste management activities (for example, collection, MRF, transportation, treatment, disposal), as well as by the processes to produce energy and material inputs that are included in the life cycle inventory. Energy offsets can result from the production of fuels or electrical energy and from the recycling of materials. Energy is an important parameter in life cycle studies, because it often drives the results of the study due to the significant amounts of air and water emissions associated with energy production.

As shown in Figures 12 and 13, the hypothetical conversion technology scenarios for the Greater Los Angeles and San Francisco Bay regions result in a large net energy savings. As compared to the alternative management scenarios, the conversion technology scenario ranges from about 2 times lower in net energy consumption when compared to the WTE scenario (the next best energy performer), and about 11 times lower that the landfill without energy recovery scenarios (the highest energy consumer). The recycling scenarios also resulted in net energy savings, although the levels were lower than the levels achieved by the conversion technology scenario and the WTE scenario.

The net energy savings attributed to the hypothetical conversion technology scenario results from the following aspects:

- Electrical energy produced by gasification and acid hydrolysis technologies, which offsets electrical energy produced in the utility sector.
- Fuels produced by acid hydrolysis and catalytic cracking, which offset the production of fuels from fossil sources.
- Materials recovered from the gasification and acid hydrolysis preprocessing steps and sent for recycling, which offsets the extraction of virgin resources and production of virgin materials.

One interesting finding was that the energy savings potential resulting from the additional materials recycling is a significant side benefit of the gasification and acid hydrolysis technologies and contributes approximately 10 to 20 percent of the total net energy savings.

The landfill scenarios without gas collection and utilization had the highest net energy consumption. Even the best-case landfill scenario (with gas collection and energy recovery) was significantly higher in energy consumption than the conversion technology scenario. The compost scenario consumed slightly less energy than the landfill scenarios without energy recovery and was higher in energy consumption when compared to the landfill scenario with gas collection and energy recovery. (Note: No offset was assumed for the compost product. Including an offset would likely drop the energy consumption to near zero and may even result in a net energy savings.)

The factors that led to the WTE scenario's high net energy savings include the electricity production offset and some steel-recycling offsets. Although the WTE scenario utilizes more MSW as feedstock than the conversion technologies, the energy offset is not as large as the offset shown by the conversion technology scenario. This is due to the greater efficiency of the conversion technologies in converting waste to energy (that is, more energy is produced per ton of waste input).

The recycling scenarios also were net energy savers, although the savings were not as large as that seen in the conversion technology and WTE scenarios. The reason for this is because even with high separation efficiencies (75 percent) at the MRF, a large portion (up to 50 percent or more) of the MSW is non-recyclable material that must be landfilled, such as food waste and non-recyclable material. Therefore, although recycling generates significant energy savings, a significant energy burden is associated with landfill disposal of the non-recyclable portion of the waste.

Nitrogen Oxide Emissions

NO_x emissions can lead to such environmental impacts as smog production, acid deposition, and decreased visibility. NO_x emissions are largely the result of fuel combustion processes. Likewise, NO_x emission offsets can result from the displacement of combustion activities, mainly fuels and electrical energy production.

The hypothetical conversion technology scenario showed the lowest net levels of NO_x emissions and resulted in a significant net NO_x emissions avoidance. Although the conversion technologies produce NO_x emissions, the net avoidance is a result of significant offsets of NO_x emissions associated with the production of energy and recovery and the recycling of materials, coupled with the low amount of NOx emissions from the gasification plants.

The only other scenario to show a net NO_x emissions avoidance was the high recycling scenario. All of the other alternative management scenarios are net NO_x producers. The landfill and compost scenarios showed the highest levels of NO_x emissions. The WTE and low- and mid-level recycling scenarios showed about one-half to one-third of the NO_x emissions levels returned by the landfill and compost scenarios. The NO_x associated with the landfill and compost scenario largely results from the collection of waste and fuel combusted by landfill and compost equipment such as graders, compactors, grinders, shredders, and windrow turners.

For the recycling scenarios, the low-separation efficiency (35 percent) system generated NO_x at levels comparable to those from the WTE scenario. Moving from the low- to mid- to high-separation efficiency MRF scenarios, NO_x emissions were greatly reduced, largely as a result of NO_x avoidance associated with the offset of virgin materials production.

Sulfur Oxide Emissions

SO_x emissions can lead to environmental impacts such as acid deposition, corrosion, and decreased visibility. Similar to NO_x, SO_x emissions are largely the result of fuel combustion processes. Likewise, SO_x emission offsets can result from the displacement of combustion activities, mainly fuels and electrical energy production, as well as the use of lower sulfur-containing fuels.

As shown in Figures 16 and 17, the WTE scenario resulted in the lowest levels of SO_x emissions and a significant net avoidance of SO_x emissions results for electrical energy production and ferrous metal recovery and recycling. The hypothetical conversion technology scenario resulted in the next lowest levels of SO_x emissions and also a net avoidance of SO_x emissions. The level of savings is approximately on par with that achieved through the 75 percent recycling scenario. The gasification system resulted in a significant SO_x savings from electrical energy offsets, whereas the catalytic cracking and acid hydrolysis technologies resulted in positive SO_x emissions. The main source of SOx emissions for the acid hydrolysis system came from the production of sulfuric acid, which is a required input for the ethanol production plant. Although catalytic cracking generated a SO_x offset, production of diesel fuel from fossil petroleum is avoided. Because of this, the SO_x emissions from the MRF operations were slightly higher than the offset.

The up and down bar pattern in the conversion technology scenario graph was a result of the addition of acid hydrolysis capacity in 2007. Because there are significant SO_x emissions associated with sulfuric acid production, when two additional acid hydrolysis plants are put on line in 2007, the net SO_x emissions savings is decreased from 2005, where only a new gasification plant is added.

The landfill with gas collection and energy recovery scenarios and recycling scenarios also exhibited net SO_x emission savings. These savings were the result of the offsets of fossil fuel production and combustion in the utility sector for the landfill scenario, as well as the virgin materials offsets associated with the recycling scenarios.

Carbon Emissions

Carbon emissions contribute to the greenhouse effect; thus, these emissions can lead to climate change and its associated impacts. Carbon emissions can result from the combustion of fossil fuels and the biodegradation of organic materials (for example, methane gas from landfills). Offsets of carbon emissions can result from the displacement of fossil fuels, materials recycling, and the diversion of organic wastes from landfills. We report carbon emissions in unit of metric tons carbon equivalent (MTCE). MTCE is derived as follows:

$$[(\text{Fossil } CO2*1 + CH4*21)*12/44] / 2000$$

As shown in Figures 18 and 19, both the WTE and hypothetical conversion technology scenarios resulted in a slight net carbon emission savings. As expected, the landfill with the gas venting scenario produced the highest levels of carbon emissions. The remaining scenarios (landfill with gas management, compost, and recycling) all produced comparable levels of carbon emissions.

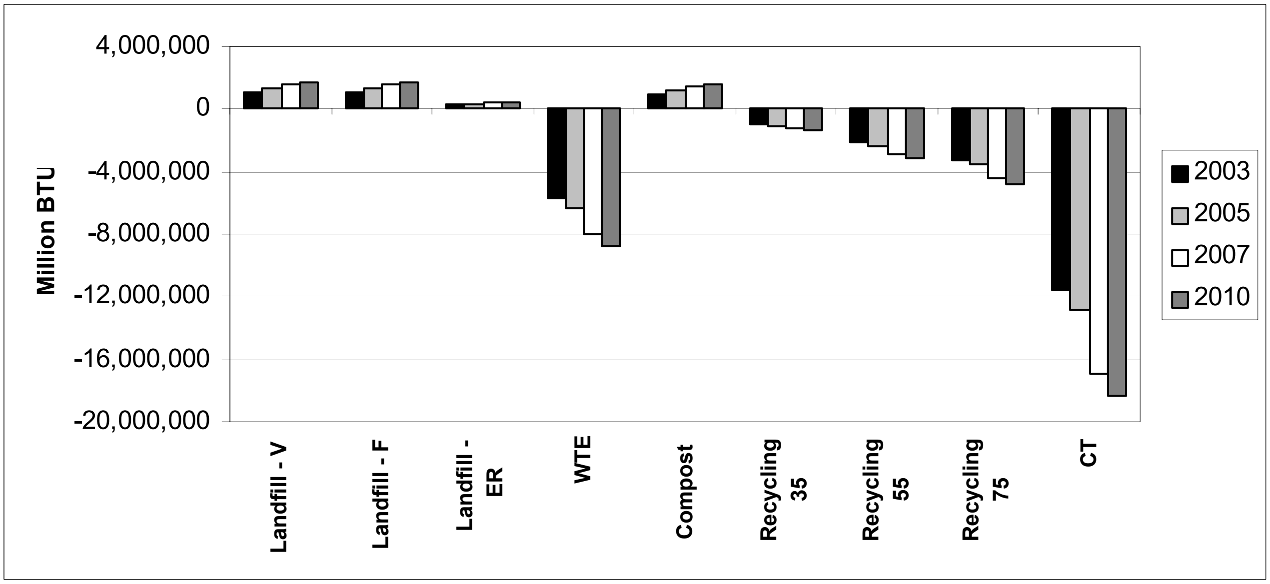

Figure 12. Greater Los Angeles Region, Annual Net Energy Consumption

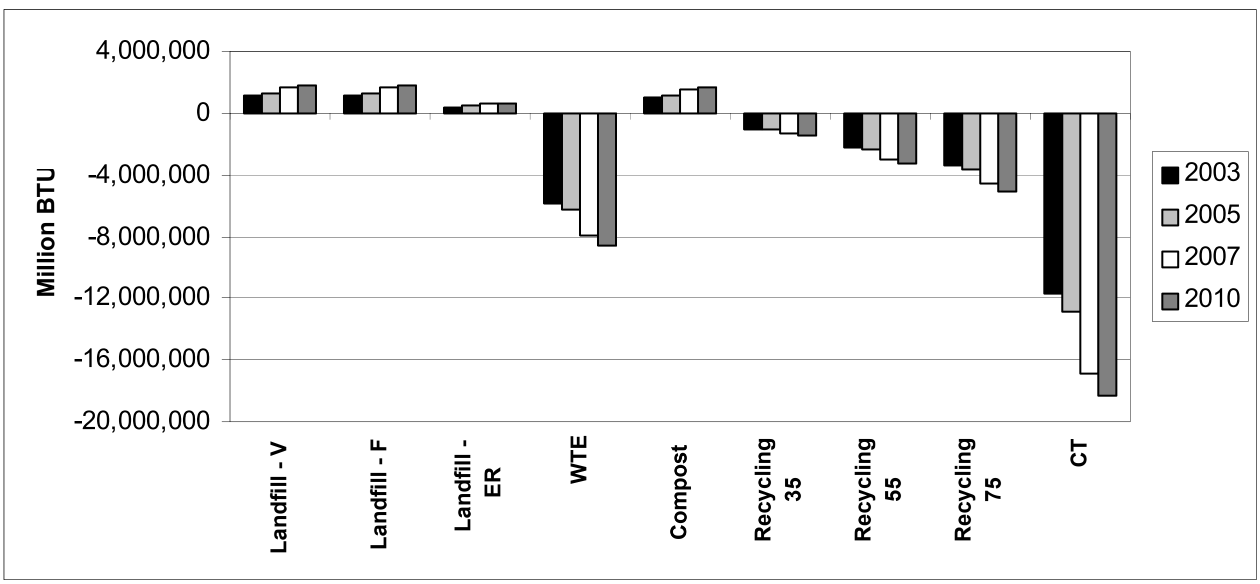

Figure 13. San Francisco Bay Region, Annual Net Energy Consumption

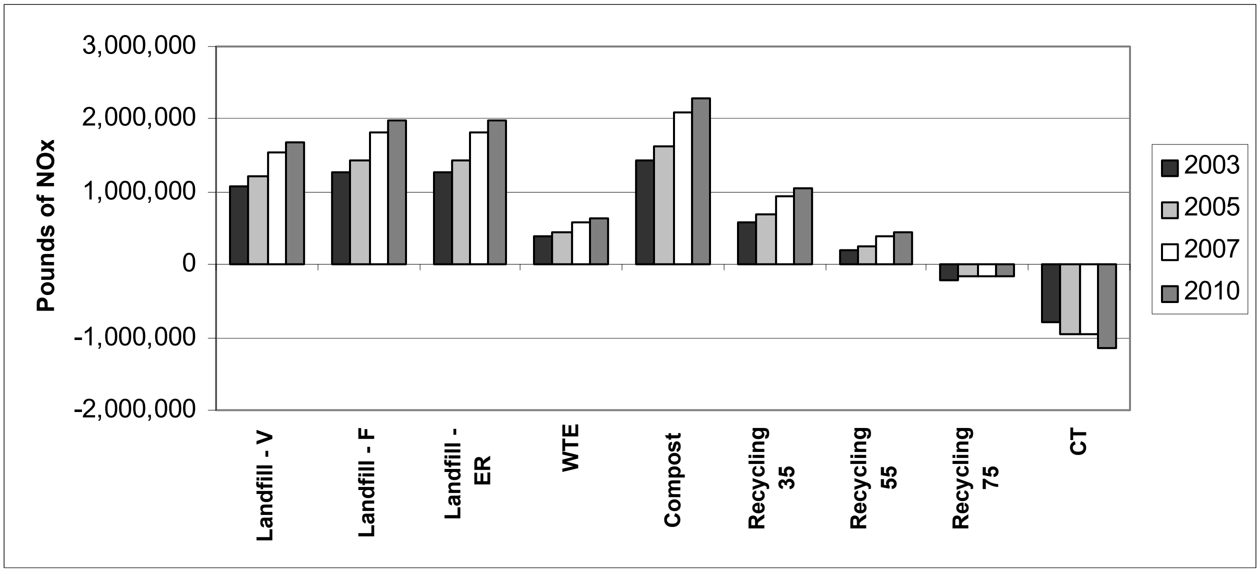

Figure 14. Greater Los Angeles Region, Annual Net NO_x Emissions

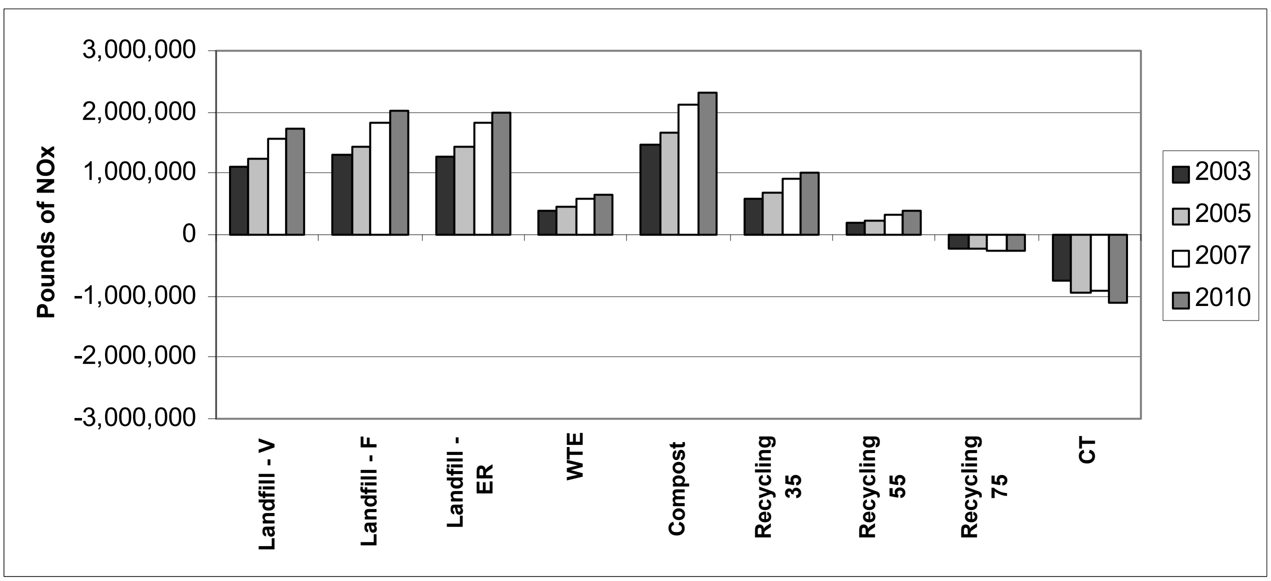

Figure 15. San Francisco Bay Region, Annual Net NO_x Emissions

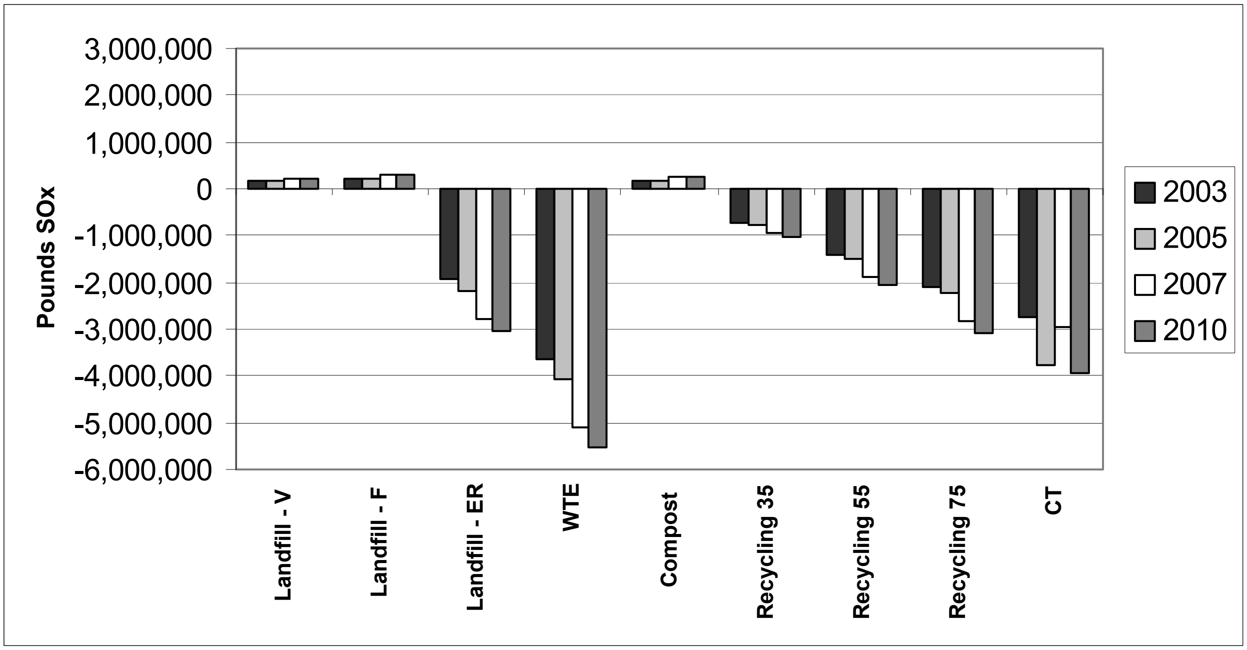

Figure 16. Greater Los Angeles Region, Annual Net SO_x Emissions

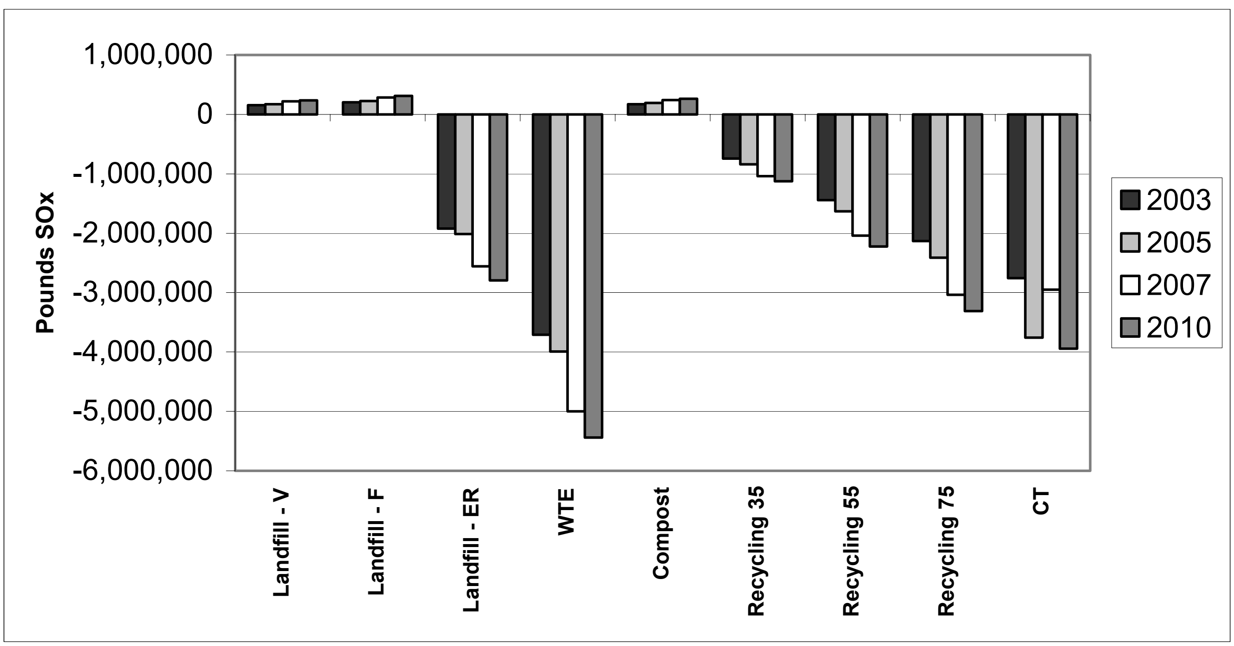

Figure 17. San Francisco Bay Region, Annual Net SO_x Emissions

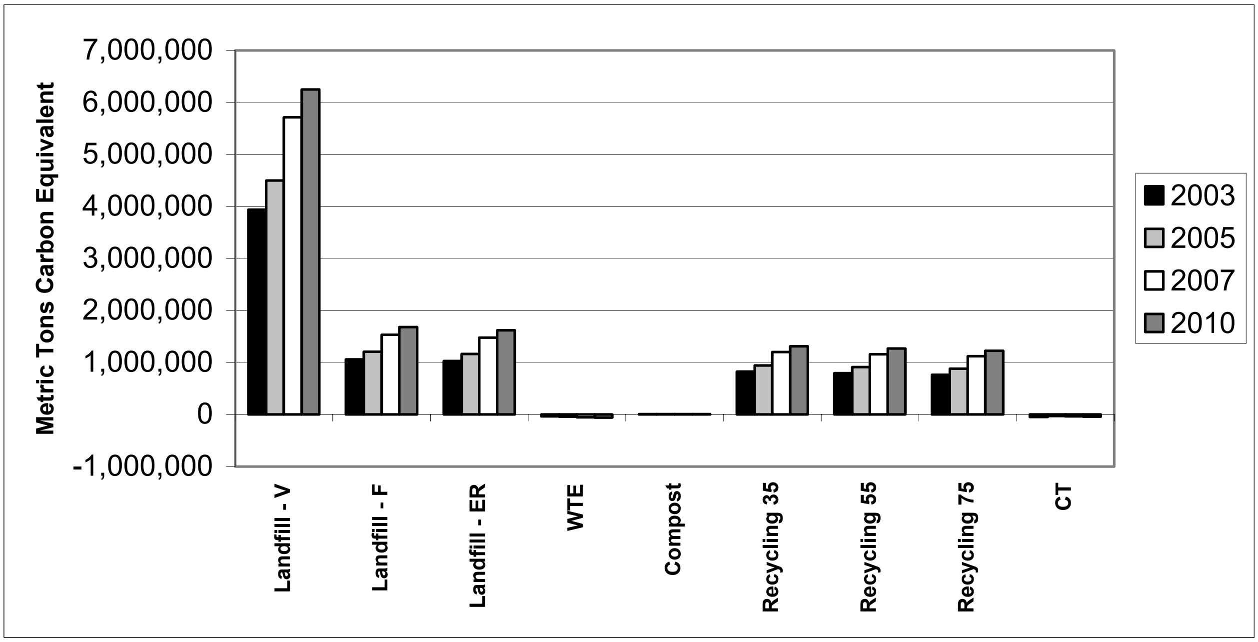

Figure 18. Greater Los Angeles Region, Annual Net Carbon Emissions

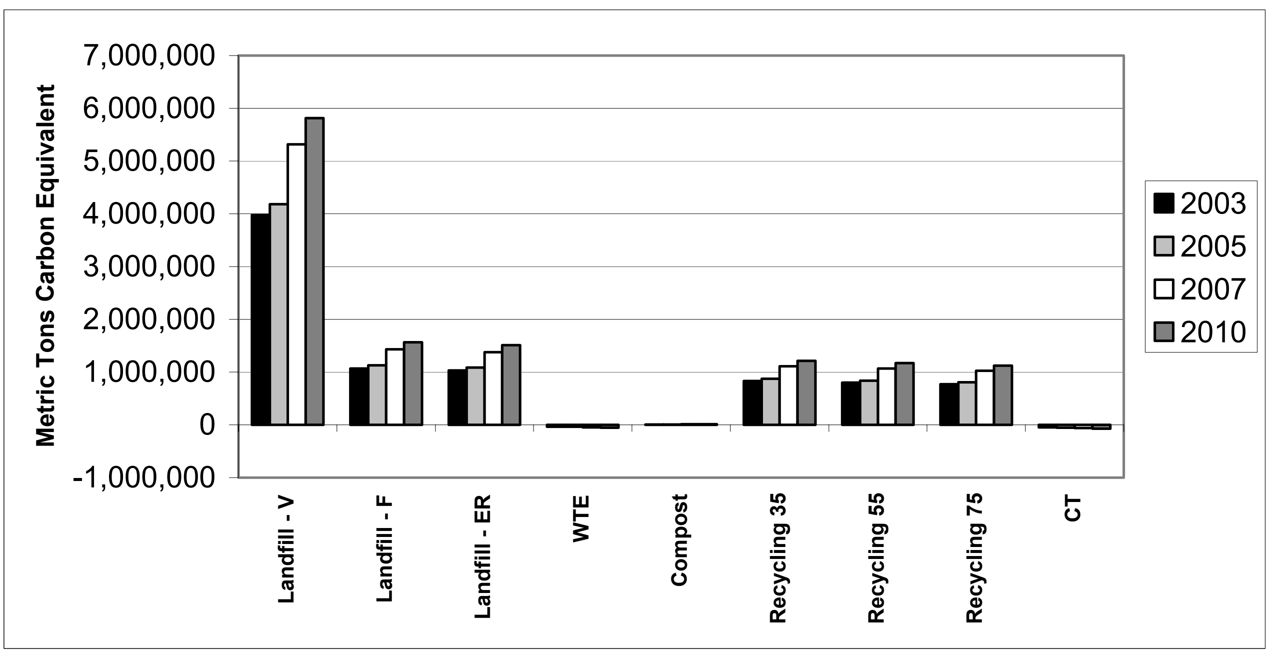

Figure 19. San Francisco Bay Region, Annual Net Carbon Emissions

Dioxin/Furans and HAPs

With respect to other pollutants of concern, such as dioxins and furans, toxics, and heavy metals, data were not available for all of the processes in each scenario to develop comparable results. In addition, test data were not available from the technology vendors to associate levels of these pollutants to specific waste constituents. Although dioxin emissions can be controlled by careful pre-sorting of feedstocks to remove PVC and other sources of chlorine, no data were available to estimate reasonable efficiencies for such efforts. We compared available data on dioxins and furans and other HAPs from conversion technology processes to existing activities that involve the combustion of wastes, coal, and landfill disposal.

As shown in Table 15, conversion technology data related to conversion technology processes were only available for gasification and acid hydrolysis. Further, the gasification data were based on a single emission test, as reported by Brightstar, and the hydrolysis data were based on permit limits for the Masada plant in Middletown, NY. Table 6 does not show any clear differences between HAP emission factors for the conversion technology processes, WTE, and coal utility boilers.

The conversion technology processes, WTE, and coal boilers all have higher emission factors for mercury than does landfilling. If landfill fires are included, the conversion technology processes, WTE, and coal boilers all have lower emission factors for dioxins and furans than does landfilling. However, if landfill fires are excluded, they have higher emission factors.

Table 15. Comparison of Dioxins and Furans and Other Hazardous Air Pollutants

Pollutant	Coal Utility Boilers[a]	WTE[b]	Landfill[c]	Gasification[d]	Hydrolysis[e]	Catalytic Cracking
Dioxins and furans[f]	1.47E-04	4.72E-04	4.78E-05 (6.87E-03)	1.42E-04	4.28E-04	No data
Lead	7.58E+01	1.70E+02	No data	No data	3.96E+02	No data
Cadmium	3.91E+00	1.19E+01	No data	1.42E+02	3.96E+01	No data
Mercury	6.23E+01	7.86E+01	6.20E-01	9.46E+01	1.58E+02	No data
Hydrochloric acid	1.64E+05	9.55E+04	No data	2.36E+04	No data	No data

[a] Emission factors for an average facility, in mg/Mg of coal fired, based on nationwide emissions data for 1994, per the U.S. EPA Utility Air Toxics Report.[12]

[b] Emission factors for a large combustor in 2000, in mg/Mg of waste fired, per Walter Stevenson of U.S. EPA.[13]

[c] Landfill values do not include potential emissions from vehicles and equipment operating at the landfills. Parenthetical value for dioxins and furans includes landfill fires.

[d] Emission factors for gasification based on concentration data reported by Brightstar.[14]

[e] Emission factors for hydrolysis based on concentration permit limits for Masada plant in Middletown, NY.

[f] Dioxin and furan values are in mg international toxic equivalents (ITEQ)/Mg of waste or coal.

Other Environmental Burdens

Data for additional air and water pollutants from each of the scenarios analyzed is included in Appendix C and above in Table 15.

Summary of Key Findings

In this section, we highlight what we feel to be the key findings from the life cycle assessment and market impact assessment. Although we used the best available information to characterize the life cycle and market impacts resulting from the hypothetical conversion technology scenarios, the conversion technologies do not yet exist in California, and we had to make a number of assumptions about their design and operating characteristics. Therefore, the findings from this study need to be taken in context and considered as general directional conclusions rather than absolute conclusions. Additional research that we feel is needed to further characterize the life cycle and market impacts from the proposed commercialization of conversion technologies is listed in Chapter Six.

The amount of energy produced by the hypothetical conversion technology scenario is larger than the alternative management scenarios studied and creates large life cycle benefits.

Energy is consumed by all waste management activities (for example, collection, MRF, transportation, treatment, disposal), as well as by the processes used to produce energy and material inputs to the conversion technologies. Energy offsets can result from the production of fuels or electricity and from the recovery and recycling of materials. As shown in Figures 12 and 13, the conversion technology scenario is much lower in net energy consumption when compared to the alternative management scenarios and is a large net energy saver. The energy savings attributed to the conversion technologies result from a combination of electricity, fuel, and materials (recycling) offsets.

The energy-savings potential resulting from the additional materials recycling ranges from 10 to 20 percent of the total net energy production potential. When comparing the alternative management scenarios, the WTE scenario significantly outperformed all others for net energy consumption. The factors that led to WTE's high net energy savings include high electricity production and some steel recycling offsets. The best-case landfill scenario (with gas collection and energy recovery) was significantly higher in energy consumption than the WTE and conversion technology scenarios.

For criteria air pollutants, the hypothetical conversion technology scenario is better when compared to the alternative management scenarios.

NO_x emissions result largely from combustion processes. Thus, NO_x offsets can result from the displacement of combustion activities, mainly fuels and electrical energy production. As shown in Figures 14 and 15, the conversion technology scenario resulted in the lowest amount of NO_x and a significant net NO_x offset. The only alternative management scenario that resulted in net NO_x offset is the high (75 percent) recycling scenario. The remaining alternative management scenarios produce net positive amounts of NO_x.

SO_x emissions are also largely a product of combustion processes. SO_x offsets can result from the displacement of combustion activities, mainly fuels and electrical energy production, as well as the use of lower-sulfur-containing fuels. As shown in Figures 16 and 17, the conversion technology scenario produced a large net SO_x offset that was comparable to the high (75 percent) recycling scenario. The landfill with gas collection and energy recovery and WTE scenarios performed better than the conversion technology scenario. A large portion of the SO_x emissions associated with the conversion technology scenario resulted not from the technologies themselves, but rather from the production of sulfuric acid used in acid hydrolysis. Catalytic cracking generates a significant SO_x offset because of its production of low-sulfur diesel.

From a climate change perspective, the hypothetical conversion technology scenario is generally better than the alternative management scenarios.

Carbon (that is, greenhouse gas) emissions can result from the combustion of fossil fuels and the biodegradation of organic materials (for example, methane gas from landfills). Offsets of carbon emissions can result from the displacement of fossil fuels, materials recycling, and the diversion of organic wastes from landfills. As shown in Figures 18 and 19, the conversion technology scenario resulted in the lowest level of carbon emissions, comparable to the WTE and composting scenarios. The primary drivers for carbon emissions in the conversion technology scenario are the residual waste that is disposed of in landfills, carbon emissions from the process steps, and carbon offsets associated with energy and materials offsets.

There are not enough data to adequately assess the potential for the hypothetical conversion technology scenario to produce emissions of dioxins, furans, and other HAPs.

With respect to other pollutants of concern (dioxins and furans, toxics, and heavy metals), data were not available for all of the processes in each scenario to develop comparable results. In addition, test data were not available from the technology vendors to associate levels of these pollutants to specific waste constituents. Instead, we compared available data on dioxins, furans, and other HAPs from conversion technology processes to existing activities that involve the combustion of wastes and coal and landfill disposal.

As shown in Table 15, data related to conversion technology were only available for gasification and acid hydrolysis. Further, the gasification data were based on a single emission test reported by Brightstar, and the hydrolysis data were based on permit limits for the Masada plant in Middletown, NY (so actual emissions would probably be lower). Table 15 does not show any clear differences between HAP emission factors for the conversion technology processes, WTE, and coal utility boilers. The conversion technology processes, WTE, and coal boilers all have higher emission factors for mercury than landfilling does. If landfill fires are included, the conversion technology processes, WTE, and coal boilers all have lower emission factors for dioxins and furans than landfilling has; however, if landfill fires are excluded, they have higher emission factors.

The environmental benefits of the hypothetical conversion technology scenario are highly dependent upon their ability to achieve high conversion efficiencies and materials recycling rates.

In terms of life cycle energy consumption, employing the conversion technologies may result in a net energy savings when compared to landfill disposal options because the conversion technologies produce energy (electrical energy and fuels), which offsets energy production from fossil sources. The magnitude of the energy-related offsets is significant and provides one of the main benefits of employing conversion technologies. In addition to energy production, acid hydrolysis and gasification technologies can lead to further materials recycling. The additional recycling is a benefit and can also be quite significant. Therefore, the more efficiently the conversion technologies can transform waste into energy (or other products) and the more effectively the technologies recover additional materials for recycling, the greater the life cycle environmental benefits.

Conversion technologies would decrease the amount of waste disposed of in landfills.

We assumed that about half of the incoming material that is removed from the conversion technology processes is recycled and the other half landfilled (except for metals, for which we assumed about 70 percent recycled and 25 percent landfilled). Because of the burdens associated with landfill disposal, the conversion technology scenario would look worse if zero recycling were assumed and much better if high rates of recycling were assumed. In addition, the life cycle assessment does not capture issues about landfill space and the potential benefits of conversion technologies in reducing the amount of needed landfill space as a result of materials recovery.

Some process waste is generated from the conversion technologies that needs to be landfilled. For example, gasification produces char that is disposed of in a landfill.

No conversion technology facilities exist in the United States for MSW. Therefore, there is a high level of uncertainty regarding their environmental performance.

There is much uncertainty about the amount of unwanted metals, glass, and plastics that the conversion technology facilities will be able to remove through the up-front separation and preprocessing steps. For this study, we assumed a 5 percent contaminant level entering the conversion technology process. Higher levels of process contaminants would result in higher levels of local pollutants.

Key Uncertainties and Variables Associated with the Life Cycle Study

In completing the life cycle inventory, we made a number of the assumptions that could vary. These could lead to an increase, decrease, or insignificant change in the inventory results. In addition, there are assumptions for which we are unable to predict how inventory results would change. In this section, we highlight what we feel to be the key variables and uncertainties that can affect the outcome of the inventory, and to the extent possible, predict how these results might change.

- **Co-locating conversion technology facilities with existing or new mixed waste MRF operations.** In this study, we assumed that the conversion technology facilities would be co-located with MRF operations that accept mixed waste. However, the conversion technologies could also be located independent of MRFs. Whether the MRF and conversion technologies are co-located or not will not significantly affect the LCI results. The main difference would be an additional transportation step from the MRF to the conversion technology, and the LCI for this transportation step will not be significant in terms of the inventory totals.
- **Considering the hypothetical conversion technology scenario and alternative scenarios separately, without attempting to identify optimal combinations.** In this study, the conversion technology scenario was predefined by the CIWMB. The scenario defined conversion technology capacities from the year 2003 through 2010 for the Greater Los Angeles and San Francisco Bay regions. No attempt was made to identify optimal combinations of conversion technologies.
- **The size and location of conversion technology facilities in the hypothetical scenario.** For this study, hypothetical sizes and locations for conversion technology facilities were assumed. The results of the LCI are largely linear; therefore, the size of the results would be relatively the same regardless of the facility size. In terms of location, the main aspect here is the waste composition. The waste composition will affect the amount of recyclables and the amount of material available for the conversion process. The results of this study would be transferable to locations with waste compositions similar to the Greater Los Angeles and San Francisco Bay regions. Locations with significantly different waste compositions would produce different results; however, the directional results between the alternative strategies (that is, landfill, WTE, recycling, compost, and conversion technology) would likely be similar.

- **Recyclables are assumed to be marketed domestically.** In this study, we assumed that recyclables are marketed domestically. There is also a strong international market for recyclables, specifically in Japan and China. Although the use of domestic versus international markets for recyclables might be significant in a study of optimal recycling strategies, in this study, the transportation step for hauling recyclables from the MRF to a remanufacturing facility is not significant when compared to the LCI totals. Shipping recyclables overseas entails further distances, but more efficient transport on a fuel-consumption basis. Also, the LCI burdens associated with the transportation step for recycling is relatively insignificant when compared to the LCI burdens (or benefits) associated with the materials-remanufacturing step. Therefore, it is not expected that incorporating some level of international markets for recyclables would significantly change the LCI results of this study.

- **No source-separated waste streams assumed as feedstock for conversion technologies (except for 50 percent of catalytic cracking).** For this study, we assumed that the material entering the conversion technology facilities is mixed MSW. The one exception is catalytic cracking, where we assumed that 50 percent of the feedstock is mixed MSW and 50 percent is source-separated plastic. The implication of this assumption is that the conversion technologies must preprocess the waste prior to use in the conversion process. This preprocessing step produces feedstock that is amenable to each technology and recovers a significant amount of recyclable materials (for example, metals) that are not amenable to use in the technologies. Non-usable and unrecovered recyclables are assumed to be disposed of in a landfill.

- **No agricultural waste, construction and demolition, or sewage sludge assumed as feedstock**. For this study, we assumed the feedstock for the conversion technology scenario came from the MSW stream. We did not analyze the use of non-municipal wastes, such as agricultural waste, C&D waste, and sewage sludge. The implications of analyzing MSW as feedstock largely resides in the additional recycling achieved by the conversion technology scenario processing MSW. If agricultural, C&D, or sewage sludge are used, there would be little or no additional materials recovery. The recycling benefits in the conversion technology scenario are approximately 10 to 20 percent of the totals.

- **Source-separated feedstock assumed for composting**. For the compost scenario, we assumed an organics-only facility, because these are the only types of compost facilities in California. We assumed that the organic material is source-separated, and the remaining, inorganic fraction is landfilled. If a mixed MSW compost facility were modeled, the results would differ by the amount of difference between the landfill and compost options.

- **National average statistics used in many cases instead of California-specific averages.** In modeling the conversion technology scenario, we relied on the technology information available from the vendors and the public literature. We assumed for the hypothetical conversion technology scenario that the facilities would be similar to the existing or described technologies devised by the vendors. For the alternative MSW management scenarios, the facility designs and operating parameters are based largely on the national average default values contained in RTI's MSW DST. Although actual design and operating parameters for facilities in California may differ from the national averages, we would expect the same directional results as obtained in this study.

Chapter 5 Market Impact Assessment Methodology and Data

This chapter presents the study methodology and the data that was gathered and compiled for this study. The following chapter, Chapter Six, presents our analysis and findings. This chapter is organized as follows:

1. **Study Definition.** Description of the overall purpose and objectives of the study.
2. **Study Approach and Methodology.** Description of the overall study approach used to gather background information about potential conversion technologies and the customers and markets that conversion technology might impact.
3. **Markets for Feedstock.** Description of the markets that supply feedstock for conversion technology facilities, such as paper, plastics, organics, landfills, and MRF residuals.
4. **Feedstock Composition.** Description of the feedstock composition requirements of the three conversion technologies under study and how we used existing waste composition data to compute feedstock requirements.
5. **Existing Institutional Relationships.** Discussion of the institutional relationships among waste haulers, jurisdictions, and solid waste facilities.
6. **Jurisdictions Interested in Conversion Technologies.** Description of efforts by California jurisdictions that are interested in perhaps using conversion technologies to process their waste streams.
7. **Conversion Technology Pricing Assumptions.** Conversion technology pricing assumptions, based on information received from vendors and jurisdictions.
8. **Job and Revenue Conversion Factors.** Description of the job and revenue conversion factors that were used in this report.
9. **Analysis of Key Background Data.** Discussion of salient data presented in this chapter.

Study Definition

Overall Purpose

Assembly Bill 2770 (Chapter 740, Statutes of 2002) requires the CIWMB to prepare a report on new and emerging technologies (such as gasification, acid hydrolysis, distillation, and catalytic cracking) to convert organic wastes to usable energy and products, collectively referred to as conversion technologies.

A significant amount of discussion has taken place through CIWMB-sponsored forums, within the CIWMB, and within the legislature regarding conversion technologies and their potential impacts on statewide recycling markets. In recognition of the concerns that were raised, AB 2770 requires the CIWMB's report on conversion technology to include "A description and evaluation of the impacts on the recycling and composting markets as a result of each conversion technology."

Economic and Financial Impact Objectives

The study's economic and financial impact objectives included the following:

- Estimate impacts on recycling and composting industries due to potential increases or decreases in feedstock supply (in tons) from new conversion technology facilities. If there is a tonnage impact, estimate the revenue gain or loss and the impact on employment levels. If there is a price impact, determine what effects the increase or decrease in prices will have in terms of total revenue.
- Estimate which technology configurations had the greatest/least impact on recycling and composting.

Institutional Impact Objectives

The institutional impact objectives were to research and provide analysis regarding the following:

- Impacts on hauler contractual relationships.
- Municipal contractual relationships.
- Effects on regional recycling and composting infrastructure and siting of new facilities.
- Effects of conversion technology put-or-pay contracts on recycling and composting businesses.

Study Approach and Methodology

The general approach was to collect data regarding the current marketplace, including quantities and compositions of various waste and recycling streams; the entities that make decisions regarding disposition of these materials (for example, generators, jurisdictions, MRF operators, and haulers); the reasons for those decisions (for example, Integrated Waste Management Act regulatory mandates, political mandates, costs, and transportation distances); and the quality and quantity needs of paper and plastic recycling processors and exporters and the composting/mulch industry. The relationships of material movement through the system were then modeled and overlaid the conversion technology system configurations, quality, composition, and price of material needs in order to estimate what might occur to the recycling and composting industries if such conversion technology facilities were developed.

General methods included identifying existing reports and articles and examining them for useable data; contacting industry associations for published reports and forecasts; collecting data from CIWMB in-house databases; compiling data from in-house databases, files and reports; and conducting surveys and interviews to collect primary data and industry expert forecasts and opinions. The reports, articles, and forecasts are cited in the text and source notes in this chapter.

In general, the work was organized into the following steps:

1. Develop conversion technology configuration assumptions and other key modeling assumptions.
2. Develop baseline projections for recycling and composting (existing and future quantities of material recovered for production or export).
3. Estimate impacts of conversion technology on recycling and composting.

A financial model was developed to input and summarize data and to perform certain calculations. A more detailed description of the financial model is included in Appendix F.

Markets for Feedstock

Potential Sources

This study looked at the possibility of using the following feedstocks for conversion technologies:

- Paper.
- Plastic.
- Organics and green waste.
- Material destined for landfilling, including materials recovery facilities' residuals.

Except where otherwise noted in Chapter Five, the conversion technologies studied are anticipated to receive feedstock destined for landfilling, not separated recyclables or green waste. The impact on recyclables markets would be from the small amount of additional diversion recovered during presorting of feedstock to prepare it for conversion technology.

Research was conducted on each of the feedstock types listed above to determine current and past pricing, as well as current and historical levels of recovery. In addition, data was gathered regarding the historical exports of paper and plastics and experts' opinions regarding the future of export markets. Price was considered one of the primary decision points in estimating what materials might become feedstock for potential conversion technology facilities; therefore, price histories and price forecasting was important to the study. The following sections of this report cover historical and projected future prices, quantities, and market forces affecting demand and pricing for the potential feedstocks, such as paper, plastic, organics, and material destined for landfilling.

Paper

Paper is an acceptable feedstock for two conversion technologies, namely acid hydrolysis and gasification. This section of the report discusses the history of tons recovered, estimates paper recycling quantities for the two regions under study, discusses the recent history of scrap paper exports from regional ports in California, and gives pricing history and projected prices for the near-term.

Quantities of Paper Recycled

Once paper is recovered from the waste stream, it may be processed at a recycling facility, sold to a paper broker, and then sent to either an in-country recycler or an exporter. The total amount of paper recovered in the United States is known through the annual tracking of processors and exporters conducted by the American Forest and Paper Association (AF&PA); however, the origin of each collection or shipment of recovered paper is not recorded. In conducting this study, we consulted with several experts from the paper industry who all agreed that no tracking system exists to estimate paper recovered from a region consisting of a group of counties in California. As a result, national recovery amounts were used and prorated to the regions under study, based on population. For paper exports, however, we report in this chapter on the quantities exported through specific ports in each of the two regions.

Based on the AF&PA's *Recovered Paper Statistical Highlights, 2003 Edition*, the amount of paper fiber recovered in the United States amounted to 47.6 million tons in 2002, representing a 34.3 percent increase from the amount recorded in 1993. On average, the amount of recovered fiber grew 3.3 percent per year between the years 1993 and 2002.

Over the last ten years, while the amount of paper fiber recovered nationally was growing, the majority of the growth was being channeled to the export market. Paper exported from the United States grew significantly, increasing by 76.8 percent from 1993 to 2002. Of the 47.6 million tons of recovered fiber reported in 2002, 25 percent or 11.3 million tons were exported (Table 16). As export of recovered fiber rose, particularly post-1999, growth in non-exported recovered fiber slowed or decreased. During the 10-year period from 1993 to 2002, non-exported recovered fiber grew an average of 2.5 percent per year, but registered an average -0.4 percent growth per year for the 5-year period from 1998 to 2002.

Table 16. Recovered Paper Tonnage in the United States (1,000 tons)

Year	Total	Exports	Total Excluding Exports
1993	35,460	6,371	29,089
1994	39,691	7,674	32,017
1995	42,189	9,908	32,281
1996	43,076	8,084	34,992
1997	43,989	7,882	36,107
1998	45,076	8,117	36,959
1999	46,818	8,517	38,301
2000	47,311	10,272	37,039
2001	46,996	10,597	36,399
2002	47,635	11,267	36,368

In 2002, recovered fiber not exported in the United States totaled 36.4 million tons. In order to approximate the number of tons from this total that are attributable to the San Francisco Bay and the Greater Los Angeles regions, we allocated tonnage based on each region's share of the U.S. population. As shown in Table 17, the Greater Los Angeles region accounted for 5.7 percent of the total national population in 2002, and the San Francisco Bay region accounted for 2.4 percent. Based on these percentages, we estimated the non-exported recovered paper tonnage to be 2.1 million tons for the Greater Los Angeles region and 0.9 million tons for the San Francisco Bay region.

Table 17: Estimates of Paper Recovered in Two Regions for Domestic Use

Area	Population[a]	% of Population	In-Country Tonnage
United States[a]	287,973,924	100%	36,368,000
Greater Los Angeles Region[b]	16,496,900	5.73%	2,084,000
San Francisco Bay Region[b]	6,994,500	2.43%	884,000

[a] United States Census Bureau, July 1, 2002
[b] California Department of Finance, Jan. 1, 2003

Nationwide recycling rates for newspaper and corrugated cardboard are currently above 70 percent, suggesting there is little room for growth. A number of jurisdictions have achieved 50 percent or more recycling goals in California, including the cities of Los Angeles and San Francisco. The statewide average diversion rate was 47 percent in 2003.

Projected future growth of paper recycling (assuming conversion technology facilities are not developed) was computed using population growth rates, rates of growth or decline of specific material types, and documented plans for increased recycling program implementation from jurisdictions. Additional growth in recycling programs is possible as a result of technology advances and the implementation of new programs, but these possibilities were not quantified for this study. In the financial model, the export growth rates and the 10-year (1993-2002) national recovered paper growth rate of 2.5 percent were used to forecast future paper tonnage growth (see Appendix F for financial models).

The two key drivers of paper recycling growth are scrap paper exports and scrap paper prices. We have examined the historical scrap paper exports and scrap paper prices in the San Francisco Bay and Greater Los Angeles regions in the following sections.

Scrap Paper Exports

Paper Export Methodology

Because the exporting of scrap paper has been an increasingly more significant force, impacting prices and availability of scrap paper in California for the last several years, and because export issues were of great interest to the focus group on the technical memorandum, a significant portion of the study efforts were devoted to scrap paper exports.

For our study, we obtained *The Paper Stock Report* and *The U.S. Scrap Paper Export Summary* for the years 1998 to 2002, published by McEntee Media Corp., Cleveland, Ohio. *The U.S. Scrap Paper Export Summary* provided the export data, both in terms of tonnage and dollar value, for the Los Angeles port areas and the San Francisco port areas. The Los Angeles port areas include the Los Angeles and Long Beach ports, whereas the San Francisco port area includes the San Francisco and Oakland ports. We also obtained the recycled paper grade definitions from the AF&PA's paper products glossary via the website: www.afandpa.org/Content/NavigationMenu/). See the glossary at the end of for a definition of paper grade terms.

Each record of every shipment in the reports detailed the following:

- Country of destination.
- Paper grade (identification of all six grades of paper).
- Tons shipped.
- Dollar value of shipment.
- Month of shipment.

We further sorted and summarized these data received according to the criteria below

- Port of origin (Los Angeles or San Francisco).
- Country of destination.
- Tons by year from 1998 to 2002.
- Dollar value of exports.
- Paper grade.

From the sorted data, we calculated.

- The tonnage and revenue for each port of origin.
- The percent of growth in tons and revenue for each port area from 1998 to 2002.
- The percent share of total exports for both ports for each destination country.
- The average dollar value per ton for each grade of scrap paper.
- The average dollar value per ton, overall by year to provide a basis for calculating a trend in the scrap paper exports going forward.

Table 18. Summary of Tons and Revenue from Export of Scrap Paper in the San Francisco Port Areas and Los Angeles Port Areas

Year	Tons (in 1,000)			Revenue (in $1,000)			Average Revenue/ Ton
	SFPA[a]	LAPA[b]	Total	SFPA	LAPA	Total	
1998	632	1,653	2,285	$54,761	$139,136	$193,897	$84.86
1999	729	1,887	2,616	63,147	168,090	231,237	$88.39
2000	1,016	2,368	3,384	91,298	245,721	337,019	$99.59
2001	1,062	2,552	3,614	71,840	187,786	259,626	$71.84
2002	1,060	2,612	3,672	75,998	212,368	288,366	$78.53
Total	4,499	11,072	15,571	$357,044	$953,101	$1,310,145	$84.14
1998–2002 % Growth	68%	58%	61%	39%	53%	49%	N/A
% of Total	29%	71%	100%	27%	73%	100%	N/A

[a]SFPA – San Francisco port areas
[b]LAPA – Los Angeles port areas

As presented in Table 18, approximately 15.6 million tons of scrap paper with a value of $1.3 billion were exported through the San Francisco port areas and Los Angeles port areas during the five-year period from 1998 to 2002. Of the 15.6 million total five-year tonnage, 71 percent originated from the Los Angeles port areas and 29 percent originated from the San Francisco port areas. In the year 2002, the amount of scrap paper exported from the Los Angeles port areas amounted to 2.6 million tons worth $212.4 million, and in the San Francisco port areas, 1.1 million tons of scrap paper was exported with a value of $76.0 million.

The average revenue per ton for both port areas for the five-year period was $84.14, ranging from a low of $71.84 per ton on average in 2001 to a high of $99.59 per ton on average in 2000. In terms of tonnage, recovered paper exports increased at a yearly average rate of 13.8 percent in the San Francisco port areas and 12.1 percent in the Los Angeles port areas during the years 1998 to 2002. A dock worker strike occurred at the West Coast ports during the fourth quarter of 2002 and reduced the amount of scrap paper exports for that year. Without the strike, the exported scrap paper growth figure in 2002 might have been higher, and the overall growth numbers for the 1998 to 2002 period might also have been higher.

Scrap paper materials were exported from the San Francisco port areas and Los Angeles port areas to 64 countries throughout the world. Based on the total five-year exports from 1998 to 2002, the 10 largest destination countries accounted for 98 percent of total scrap paper exports. China captured the lion's share of the recovered fiber export market at 62 percent in 2002 and 48 percent of the five-year total from 1998 to 2002 (see Table 19). Total scrap paper exports grew 1.4 million tons or 61 percent during the five-year period, mainly propelled by the strong growth in exports to China that had tripled from 740 million tons in 1998 to 2.3 millions tons in 2002. Scrap paper export grew despite a net decline in exports to the other nine destination countries.

Table 19. Summary of Exports by Country for the Ten Largest Destination Countries 1998–2002 (1,000 tons)

Country	1998	1999	2000	2001	2002	5-Year Total	% of Grand Total	% Growth 1998-2002
China	740	867	1,350	2,207	2,285	7,449	48%	209%
Rep. of Korea	645	774	801	546	518	3,284	21%	-20%
Japan	217	235	224	168	137	981	6%	-37%
Indonesia	105	168	363	186	159	981	6%	51%
Taiwan	173	151	179	122	172	797	5%	0%
India	200	187	145	147	113	792	5%	-44%
Thailand	81	105	120	104	154	564	4%	90%
Philippines	46	61	79	58	45	289	2%	-2%
Hong Kong	13	30	36	8	6	93	> 1%	-54%
Bangladesh	6	5	6	13	12	42	> 1%	100%
Total Top Ten	2,226	2,583	3,303	3,559	3,601	15,272	98%	62%
Other Countries	59	33	81	55	71	299	2%	20%
Grand Total	2,285	2,616	3,384	3,614	3,672	15,571	100%	61%

According to the article entitled "The Great Haul of China" by Randy Woods in *Waste Age*, April 2004, China's expanding economy is creating a huge demand for recycled materials—including scrap paper—as the country modernizes. The country has invested a tremendous amount in building paper mills, thereby requiring large amounts of imported recycled fiber. Additional capacities to process corrugated containers and mixed paper are expected to increase by 3.5 million tons in 2004 as more processing lines come on-stream. Other articles and presentations by paper industry experts echo this content. In summary, all sources indicate that China has built and is continuing to build the capacity to recycle paper, but that the actual paper fiber must be imported for the foreseeable future.

Table 20. Summary of Exports from the San Francisco Port Area

Year	Recycled Paper Grades (1,000 tons)						Total
	Chemical Pulp	Corrugated Containers	Deinking	Mechanical Pulp	Mixed Paper	Newsprint	
1998	36	188	68	61	149	130	632
1999	58	136	68	78	250	139	729
2000	48	186	68	62	429	223	1,016
2001	26	211	85	48	460	232	1,062
2002	39	227	43	59	499	193	1,060
Total	207	948	332	308	1,787	917	4,499
% of Total	5%	21%	7%	7%	40%	20%	100%
Growth	8%	21%	-37%	-3%	235%	48%	70%

Table 21. Summary of Exports from the Los Angeles Port Area

Year	Recycled Paper Grades (1,000 tons)						Total
	Chemical Pulp	Corrugated Containers	Deinking	Mechanical Pulp	Mixed Paper	Newsprint	
1998	232	631	108	107	256	319	1,653
1999	292	553	116	135	369	422	1,887
2000	284	775	141	151	660	357	2,368
2001	97	704	137	180	1,120	314	2,552
2002	95	818	63	192	1,119	325	2,612
Total	1,000	3,481	565	765	3,524	1,737	11,072
% of Total	9%	31%	5%	7%	32%	16%	100%
Growth	-59%	30%	-42%	79%	337%	2%	58%

Table 22. Summary of Exports from the San Francisco Port Area and Los Angeles Port Areas Combined, by Paper Grade

Year	Recycled Paper Grades (1,000 tons)						Total
	Chemical Pulp	Corrugated Containers	Deinking	Mechanical Pulp	Mixed Paper	Newsprint	
Total port areas							
1998	268	819	176	168	405	449	2,285
1999	350	689	184	213	619	561	2,616
2000	332	961	209	213	1,089	580	3,384
2001	123	915	222	228	1,580	546	3,614
2002	134	1,045	106	251	1,618	518	3,672
Total	1,207	4,429	897	1,073	5,311	2,654	15,571
% of Total	8%	28%	6%	7%	34%	17%	100%
Growth	-51%	28%	-40%	49%	300%	15%	61%

As shown in Table 22, mixed paper, corrugated containers, and newsprint accounted for 79 percent of total scrap paper exports from the San Francisco and Los Angeles port areas over the five-year period from 1998 to 2002. Export of mixed paper had increased by fourfold to 1.6 million tons in 2002, compared to 0.4 million tons in 1998. The growth in exported mixed paper accounted for the bulk of the total exported scrap paper growth of 1.4 million tons from 1998 to 2002.

Table 23. Summary of Export Revenue by Port Area and by Paper Grade

	Recycled Paper Grades						Total
	Chemical Pulp	Corrugated Containers	Deinking	Mechanical Pulp	Mixed Paper	Newsprint	
($1'000)							
SFPA[a]	$23,691	$84,676	$46,160	$44,332	$87,823	$70,362	$357,044
LAPA[b]	123,227	288,576	77,480	111,871	242,802	109,145	953,101
Total Revenue	$146,918	$373,252	$123,640	$156,203	$330,625	$179,507	$1,310,145
(in $)							
Average Revenue/ Ton	$121.72	$84.27	$137.84	$145.58	$62.25	$67.64	$84.14

[a]SFPA – San Francisco port areas
[b]LAPA – Los Angeles port areas

Table 23 summarizes the total export revenue by recycled paper grade, port of origin, and average revenue per ton for the five-year total from 1998 to 2002. The San Francisco port areas generated a total of $357.0 million in scrap export revenue, and the Los Angeles port areas registered $953.1 million during the five-year period. Of the total $1.3 billion total scrap paper export revenue, corrugated containers accounted for the largest proportion at 28.5 percent, followed by mixed paper at 25.2 percent. The average revenue per ton ranged from a low of $62.25 for mixed paper to a high of $145.58 per ton for mechanical pulp, with an overall average revenue per ton of $84.14 for the two study areas.

Scrap Paper Prices

Paper Prices Methodology

Historical scrap paper price data were collected in order to observe the pricing trends, and along with other data, to forecast future price trends. We obtained scrap paper prices from *The Paper Stock Report* for the years 1992 to 2003, published by McEntee Media Corp., Cleveland, Ohio. The report detailed bi-weekly prices per ton for the following ten grades of recycled scrap paper:

- Mixed paper.
- Mixed office paper.
- Sorted white ledger.
- Sorted color ledger.
- Computer printout (CPO), laser-free.
- Computer printout (CPO), with laser.
- Old newspaper.
- Old corrugated.
- Old corrugated, supermarket bales.
- Old magazines.

Based on the data received, we calculated the following:

- The average price per ton, per year by paper grade from 1992 to 2003.
- The projected average annual price per year by paper grade from 2004 to 2010, using Microsoft Excel's "linest" function. The linest function uses the "Least Squares" method to estimate a trend line based on given data.

Our projections of the scrap paper prices were based on historical prices using an acceptable statistical methodology to project future prices. The actual results will usually differ from projections because events and circumstances frequently do not occur as expected, and the differences may be significant.

Paper Price Summary

Scrap paper prices are subject to significant price swings. In some cases (certain grades in certain years), the high price for a given year is twice that of the low price for a given year. The following chart shows average annual prices for each grade, meaning that each point on the graph represents the annual average price for that grade for that year. The annual averaging significantly smoothes the graph, yet it still shows significant price spikes in prices for all scrap paper grades from 1995 to 2000. We anticipate that this volatility will continue in the future.

Actual prices per ton (annual averages) in 2003 ranged from $12.50 per ton for mixed paper to $105 per ton for CPO (laser print-free). Projected prices per ton for 2010 range from $17.99 per ton for sorted colored ledger to $118.38 for CPO.

These forecasting methods are not meant to provide exact price values; they are meant to provide an overall price trend that can help to predict whether or not scrap paper will be an attractive feedstock for conversion technology facilities.

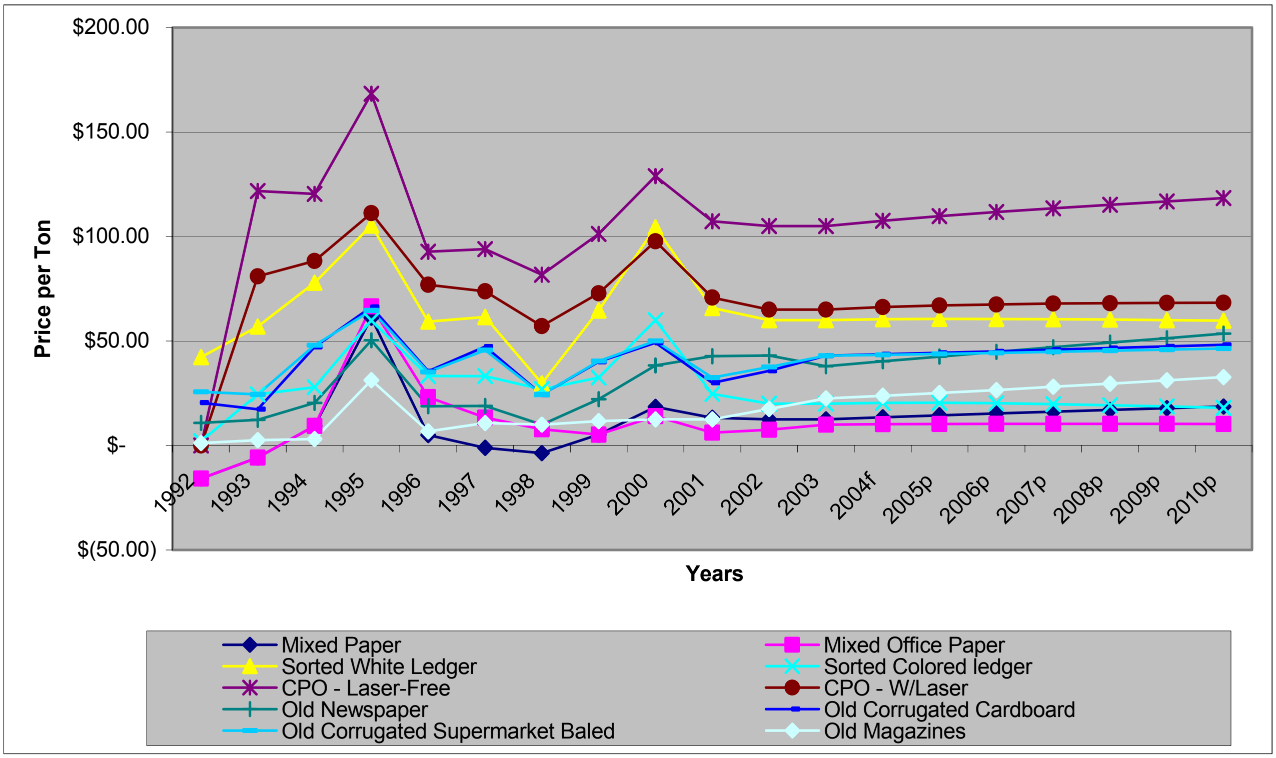

Figure 20. Average Annual Scrap Paper Prices: 1992–2003 (Actual), 2004–2010 (Projected)

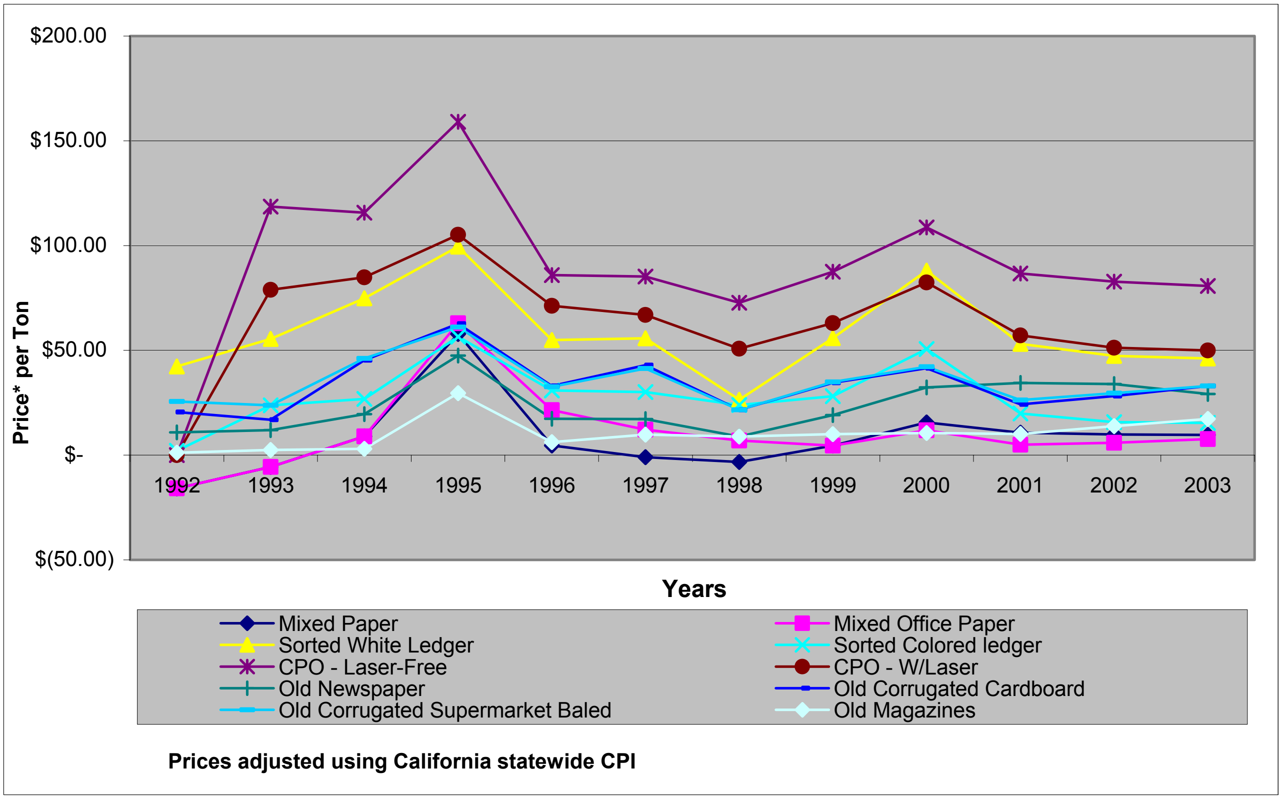

Figure 21. Inflation-Adjusted Average Annual Scrap Paper Prices: 1992–2003 (Actual)

Plastics

Estimate of Quantities of Plastics Recycled

We conducted research on scrap plastics to determine current and past pricing, as well as current and historical levels of recovery. Export data for plastics was not available to the same level as export data for scrap paper. The objective was to determine whether or not scrap plastics would be a suitable and desirable feedstock for conversion technology facilities. Similar to paper, regional plastics recycling tracking systems do not exist. We therefore sought to estimate plastics recycling tonnages from the two study regions using statewide data that had previously been compiled for the CIWMB, along with California's Bottle Bill data.

The California section of a study prepared by R.W. Beck, *U.S. Recycling Economic Information Study*, July 2001, estimated recycled plastic tonnage from California reclaimers at 234,000 tons for the year 2000. The source of that estimate was R.W. Beck's previous development of the American Plastics Council's Handler & Reclaimer Database, and the estimate includes all types of plastics that were recycled, including bottle bill plastics.

Recent changes in California's Bottle Bill expanded the types of plastic containers covered by the bill. As of January 2000, non-carbonated beverage containers were added to the list of containers covered by the Bottle Bill. From 2000 through 2003, plastic tonnage recovered under the Bottle Bill has increased by 18.8 percent per year. This cannot be viewed as entirely new recycling because many of the newly included containers may have already been recycled prior to the implementation of the updated Bottle Bill.

In 2000, California had 234,000 tons of plastics recycled, of which 88,269 tons were California Redemption Value (CRV) containers. From 2000 to 2003, the number of CRV containers increased by 59,866 tons, from 88,269 to 148,135 tons. This significant increase was primarily due to revisions to the Bottle Bill that went into effect on January 1, 2000 and January 1, 2001, thereby encouraging additional recycling in order to recover the new bottle deposits.

In order to estimate the amount of plastics recycled in the state in 2003, we added the additional 59,866 tons of CRV containers recycled from 2000 to 2003 to the 2000 state total of 234,000 tons. Subsequently, we adjusted the remaining non-CRV container portion of 145,731 tons (2000 total tonnage of 234,000 minus 88,269 Bottle Bill tons) by the 5.56 percent growth rate in the California state population for the period July 1, 2000 to July 1, 2003, to 153,834 tons. The 2003 recycled plastics tonnage for California is thereby estimated to be 301,969 tons (88,269 plus 59,866 plus 153,834). In 2002, the Greater Los Angeles region represented 46 percent of California's population, and the San Francisco Bay region represented 20 percent. Applying these percentages to California's total estimated tonnage of 301,969 tons in 2003, recycled plastics tonnage for the Greater Los Angeles and the San Francisco Bay regions would be 138,906 and 60,394 tons, respectively.

Growth Rates and Export Quantities

According to the Plastics White Paper, *Optimizing Plastics Use, Recycling, and Disposal in California*, May 2003, prepared for the CIWMB, the national production of plastics has grown at a rate of 4.9 percent per year since 1973. However, plastics recycling growth has lagged production growth.

California's recycling rate for rigid plastic packaging containers (RPPC) was reported at 23.9 percent in 2003. The recycling rate has fluctuated with modest improvement, ranging from 17.9 percent in 1999 to 26.1 percent in 2001. The average recycling rate was 22.4 percent from 1995 to 2001; however, the actual tons recycled have increased steadily from a low in 1997, with an overall annual increase of 6.7 percent from 1995 to 2001.

In the 1997 report *Solid Waste Management at the Crossroads*, Franklin and Associates forecast a 7 percent plastics recycling rate for all plastics nationwide in 2000 (actual recycling rate was 6 percent in 1999) and 10 percent rate in 2010. An increase in recycling rate from 7 percent to 10 percent over 10 years translates to a 3.6 percent increase per year in tons recycled. The overall growth in plastics production since 1973 has been 4.9 percent (see above). Combined growth due to both production and recycling results in an annual increase of 8.7 percent in plastics recycling tons.

Much of the recent growth in plastics recycling could be attributed to the demand in China. According to Waste News in its March 15, 2004 issue, the amount of PET collected for recycling in the United States has held steady for several years at about 400,000 tons. However, exports, mainly to China, have risen sharply from 45,000 tons in 1998 to 137,500 tons in 2002. The demand from China could vary tremendously and unpredictably. As with paper recycling, this export factor would have a far greater and less predictable or controllable effect on plastics recycling in California, compared to the conversion technologies proposed in this study.

Plastics Pricing

Similar to scrap paper, the recycled plastic market is also characterized by significant price volatility. It is anticipated that this volatility will persist in the future. Figure 22 shows average annual prices for four grades of recycled plastics: PET, colored high density polyethylene (HDPE), combination HDPE, and natural HDPE. Each point on the graph represents the annual average price for that grade in a particular year. The average annual price for PET ranged from

7.69 cents per pound to 15.15 cents per pound from 1996 to 2003. The average annual price for PET was 10.40 cents per pound over the eight-year period. The average annual price for colored HDPE was 7.06 cents per pound over the same period, whereas the average annual price for combination HDPE was 7.17 cents per pound from 1998 to 2001. Natural HDPE had the highest annual average price at 14.34 cents per pound from 1996 to 2003. Figure 23 shows the Consumer Price Index (CPI) inflation-adjusted prices using 1996 constant dollars.

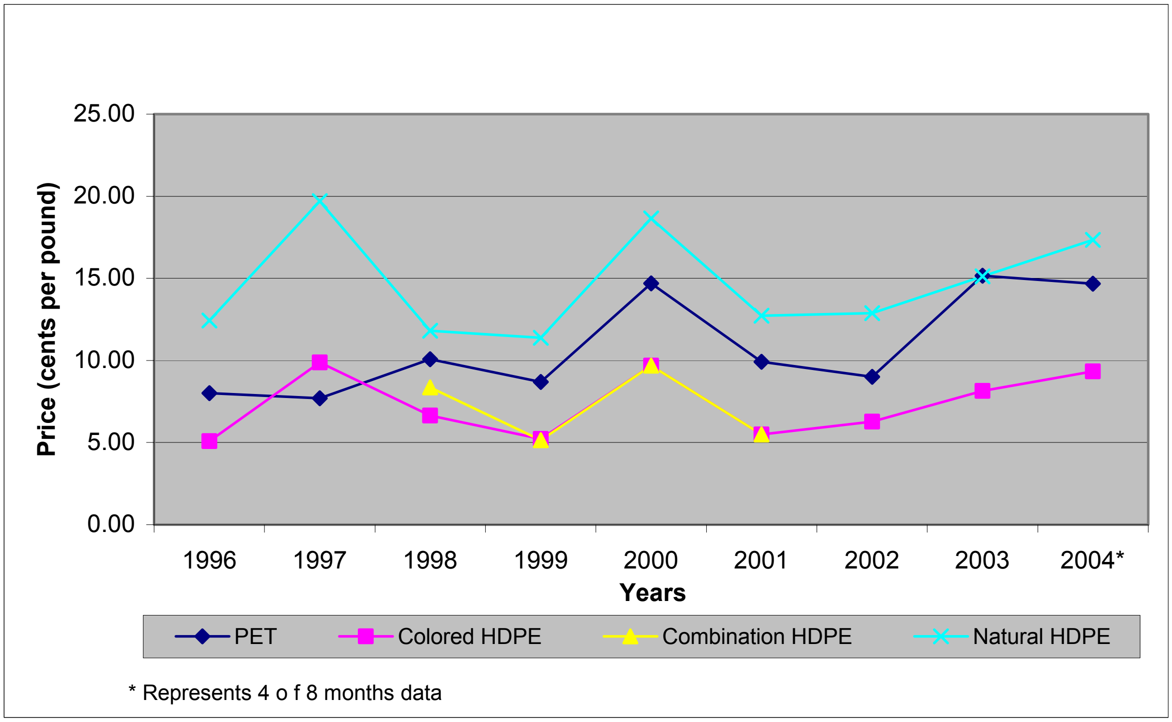

Figure 22. Los Angeles Annual Average Recycled Plastic Prices

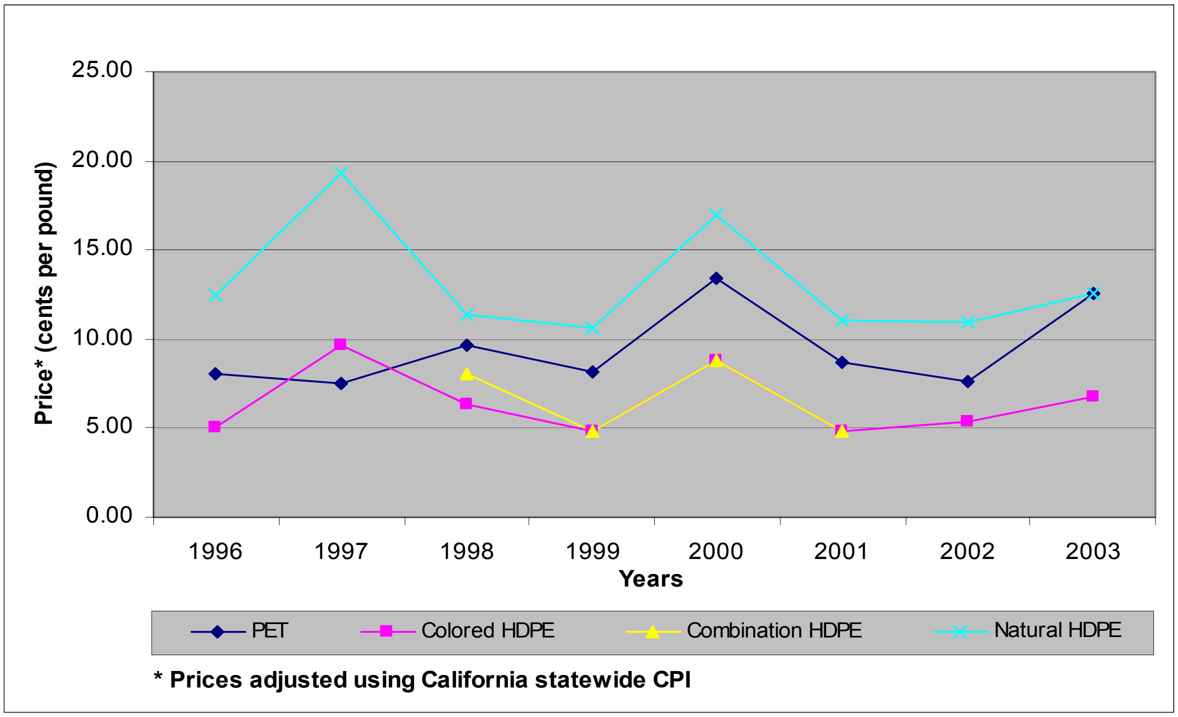

Figure 23. Inflation-Adjusted Los Angeles Annual Average Recycled Plastic Prices

Organics

Quantities of Organics Recycling

Research was conducted on organics to determine current and past pricing and current and historical levels of recovery. Organics are not exported. The objective was to determine whether or not organics would be a suitable and desirable feedstock for conversion technology facilities. The CIWMB commissioned the *Second Assessment of California's Compost- and Mulch-Producing Infrastructure,* published in May 2004.

The *Second Assessment of California's Compost- and Mulch-Producing Infrastructure* included a survey of every green waste processor in the state. Eighty one percent of the operating facilities responded to the survey and provided very good estimates of the total amount of materials processed. The state was divided into five regions, and data were published on a regional level. The categories of data included:

- Types of feedstock accepted by facilities, in tpy.
- Total quantity of feedstock accepted per year.
- Processing capacity, in tpy.
- The major sources of feedstock, including municipal collection, private contracted collection, MRF-generated, and self-haul.
- Changes in processing capacity in the last year.

- Issues related to increases in air quality permit requirements in the Greater Los Angeles region, under the South Coast Air Quality Management District's (SCAQMD) Rule 1133.
- Competitive issues related to the use of green waste for ADC.

The updated study will provide the tons received at compost- and mulch-producing facilities, including facilities that provide material for ADC, throughout the State of California. The contractor that completed the studies, Integrated Waste Management Consulting (IWMC), extracted data from the two regions that were defined for this study in order to provide the total tons of green waste material collected and processed in each region. Tonnage results are shown in Table 24 and listed as Total 2003 Tonnage. IWMC also performed additional follow-up surveying to get pricing data for a sampling of facilities.

Organics Growth Rates

The most comprehensive look at the recovery of organics in California may be contained in these two CIWMB studies. The organics included in these studies can be sent to various types of facilities, including compost- and mulch-producing facilities, as well as to landfills for use as ADC. Eleven facilities did not respond to the surveys conducted in 2001, and 32 firms did not respond in 2003 (the survey was conducted in 2003; the report was finalized and published in 2004). The same facilities did not respond under each study. Statewide totals were adjusted for the non-responsive firms in 2003. Growth in total statewide tonnage can be estimated from a comparison of these two studies, with the caveat that the totals include an estimate for non-reporting firms in 2003.

Recovery of organics generally has not shown the growth of other recyclable materials. Most cities likely to implement programs for curbside collection of green waste have already done so in order to meet requirements of the Integrated Waste Management Act. Xeriscaping (landscaping that requires less water and generates less green waste) has grown in popularity; therefore, green waste from current landscapes may be decreasing. Cities are also attempting to implement food waste collection programs, which may increase the amounts collected.

New homes are being built with smaller yards or no yards. Though population and housing will continue to grow, new landscaping is unlikely to grow in the same proportion. In estimating recovery of organics tonnage to grow at half the pace of population growth, tonnage may increase as shown in Table 24.

Table 24. Projected Increase in Organic Tonnage Recovered

Region	2003	2010
Greater Los Angeles	3,126,503	3,313,236
San Francisco Bay	1,731,747	1,866,594

Other Factors Affecting Green Waste Markets

The use of green waste as ADC has been a significant factor affecting the composting markets in the State, and as certain landfills close in the years 2004 to 2010, more green waste will be available to either the compost market or elsewhere.

Most of the Greater Los Angeles region that was defined for this study is located within the South Coast Air Quality Management district (SCAQMD). The SCAQMD has established Rule 1133 to monitor and reduce emissions from compost facilities. More stringent requirements may be imposed in future years, and compliance with more stringent requirements would be very costly to compost producers, perhaps driving them out of business or to locations outside of the air district.

Relative tipping fees (disposal costs) have also been a challenge for compost- and mulch-producing facilities. In many cases, green waste can be accepted for use as ADC at landfills at lower tipping fees and can receive diversion credit. Most jurisdictions are indifferent to the use of green waste as long as the use receives diversion credit, but a few jurisdictions specify that green waste be used to produce compost or mulch, not ADC. Also, because green waste tipping fees are only slightly lower than landfill tipping fees, there is not a strong economic incentive to implement separate collection systems, especially in the commercial sector, to remove green waste from the waste stream. Generally, the extra cost of separate collection for green waste would outweigh the small savings from lower green waste tipping fees.

Organics Compost, Mulching, and ADC Pricing

The larger facilities were surveyed regarding their posted and contract tipping fees and tonnage received at each rate for the year 2003. Ten responses were obtained from facilities in each area studied. This data sample was extrapolated to all tonnage, based on the percentage of the total tonnage determined above and is shown in Table 25.

Table 25. Percentage of Organics Recovered that were Represented in the Tipping Fee Survey

Region	Tonnage from Tipping Fee Survey – 2003	% of Total 2003 Tonnage
Greater Los Angeles	1,131,220	37%
San Francisco Bay	924,308	57%

Based on the survey results, we grouped the estimated number of green waste tons based on the range of tipping fees reported in 2003. These tipping fees are from facilities that compost, mulch, and use green waste for ADC (Table 26 and Table 27).

Table 26. Green Waste Tons Available at Various Tipping Fees in the Greater Los Angeles Region

Tip Fee Per Ton	Green Waste Tons	% of Total
$0.00 to $10.00	-	-
$10.01 to 20.00	1,598,762	52%
$20.01 to $30.00	1,003,995	33%
$30.01 to $40.00	454,594	15%
$40.01 to $50.00	-	-
Total	3,057,351	100%

Table 27. Green Waste Tons Available at Various Tipping Fees in the San Francisco Bay Region

Tip Fee Per Ton	Green Waste Tons	% of Total
$0.00 to $10.00	-	-
$10.01 to 20.00	495,768	31%
$20.01 to $30.00	735,923	45%
$30.01 to $40.00	389,901	24%
$40.01 to $50.00	-	-
Total	1,621,592	100%

The *Second Assessment of California's Compost- and Mulch-Producing Infrastructure,* published May 2004, shows the following estimates of green waste used as ADC (Table 28).

Table 28. Green Waste used as Alternative Daily Cover in 2003

Region	Total Green Waste Tons	% Used as ADC
Greater Los Angeles*	3,051,292	31%–75%
San Francisco Bay	1,623,254	27%– 35%

* Estimate is for region including Imperial, Inyo and San Diego counties, as well as Los Angeles, Orange, Riverside and San Bernardino counties.

The data was collected through a blind survey in order to preserve the respondent's confidentiality. However, we are able to ascertain that the lowest tip fee rates in the Greater Los Angeles region to be $11 per ton, $12.10 per ton, and $13.75 per ton are for facilities that use the material as ADC.

Landfill Disposal Analysis

The landfill market was studied to determine whether these materials would be suitable and desirable feedstock for conversion technology facilities. The availability of capacity, historical and current pricing, and overall quantities (current and future) are describe. In addition, the future pricing at some facilities is known because certain portions of the waste stream are governed by publicly available contracts were quality and price information is available.

There are 21 landfills accepting MSW in the nine-county San Francisco Bay region and 29 landfills in the four-county Greater Los Angeles region. In 2002, disposal tonnages reported for the San Francisco Bay region and Greater Los Angeles region were approximately 6.8 million tons and 18.1 million tons, respectively.

Current and Projected Disposal Tonnage

Waste disposal quantities are currently tracked by the CIWMB for every jurisdiction and landfill in the state using the Disposal Reporting System. Yearly totals are available for each jurisdiction and landfill. By adding up the annual totals for each landfill within the region, we obtained the San Francisco Bay region and the Greater Los Angeles region disposal totals for 2002.

Disposal tonnage by disposal facility was projected, starting with the actual tonnage for each facility as reported to the CIWMB. To project the disposal growth rates, we compiled the existing and projected population numbers from the California Department of Finance for each of the 13 counties and calculated the annual percentage population growth rate for each of the two regions. We then projected disposal quantities for each year from 2003 to 2010, using population percentage growth factors. Disposal tonnage was projected to grow by 11.8 percent to 7.6 million tons in the San Francisco Bay region and 11.0 percent to 20.1 million tons in the Greater Los Angeles region in 2010.

The closure of disposal facilities was also projected, assuming the closure date provided in the CIWMB Solid Waste Information System (SWIS) facility database, unless industry knowledge of specific facilities provided a better or more accurate result. Disposal tonnage from closed facilities was assumed to go to a facility with the median tipping fee for the particular county, unless industry knowledge of the diversion of tonnage from closed facilities to specific disposal facilities provided a better or more accurate assumption.

Six landfills in the San Francisco Bay region are expected to close over the next few years; three in 2004, with approximately 4,000 tons of permitted daily capacity, and three in 2005, with approximately 5,000 tons of permitted daily capacity (Table 29).

Six landfills in the Greater Los Angeles region are expected to close by 2007, with approximately 18,380 tons of permitted daily capacity (Table 30).

Table 29. Expected Landfill Closures in the San Francisco Bay Region, 2003 to 2010

Year	Landfill	Permitted Daily Tons
2004	Acme Landfill	1,500
	Pacheco Pass Sanitary Landfill	1,000
	Zanker Road (Nine Par) Sanitary Landfill	1,300
2005	Durham Road Sanitary Landfill	2,300
	West Contra Costa Sanitary Landfill	2,500
	Hillside Solid Waste Disposal Site	400
Total Reduction in Capacity		9,000

Table 30. Expected Landfill Closures in the Greater Los Angeles Region, 2003 to 2010

Year	Landfill	Permitted Daily Tons
2004	Edom Hill Landfill	3,000
2005	Victorville Refuse Disposal Site	1,600
	Mecca Landfill I	400
2006	Colton Refuse Disposal Site	3,000
	Bradley Avenue West Sanitary Landfill	10,000
2007	Landers Disposal Site	400
Total Reduction in Capacity		18,400

There is adequate excess capacity in the remaining facilities in both the San Francisco Bay region and Greater Los Angeles region to accommodate the additional projected daily tonnage stemming from the expected landfill closures.

Tipping Fees

Because there are a variety of fees at each disposal facility, the tipping fee presented represents the fee for regular MSW only (not hard-to-handle waste, green waste, or other categories). The tipping fee for a number of the disposal facilities was stated as dollars per cubic yard. The cubic yard rate was converted to a tonnage rate assuming 500 pounds per cubic yard, unless the resulting fee was determined to be unreasonable. For instance, if the conversion of the cubic yard rate resulted in a per ton fee of $80 and tipping fees at nearby disposal facilities were in the region of $60, we assumed the lower per-ton rate.

Data Sources and Uses

During our study, we obtained various information from the following sources:

- CIWMB Web site, SWIS database for disposal facilities.
- Telephone survey of disposal facilities.
- Research of Web sites for individual disposal facilities.
- U.S. Bureau of Labor Statistics.
- Consumer Price Indices—All Urban Consumers—All Items for: San Francisco-Oakland-San Jose, Calif. and Los Angeles-Riverside-Orange County, Calif.
- Producer Price Index—Commodities—Industrial Commodities.
- Employment Cost Index—Total Compensation—Private Industry.
- California Department of Finance—Population Projections.
- Municipal and governmental agency landfill contracts for various facilities in the San Francisco Bay and Greater Los Angeles regions.

The following are the data received for the active landfills in the San Francisco Bay and the Greater Los Angeles regions:

- Posted, contract (if available), and import (if applicable) tipping fees.
- Actual tonnage reported to the CIWMB for calendar year 2002.
- Estimated landfill closure dates.
- Consumer price indices.
- Producer price index.
- Population statistics.

We sorted and summarized the information obtained according to the following:

- San Francisco Bay and Greater Los Angeles regions.
- Actual and projected tipping fees for 2003 through 2010.
- Actual disposal tons for 2002 and projected tons for 2003 through 2010.
- Projected disposal cost for 2003 through 2010.

From the data received, the following was calculated:

- The projected tipping fees by disposal facility for 2003 through 2010.
- The contract tipping fees by disposal facility (if the contract tipping fee was not available).
- Projected disposal tonnage by disposal facility for 2003 through 2010.
- Projected disposal cost by disposal facility for 2003 through 2010.

The following were the assumptions made to project tipping fees and disposal tonnage for 2003 to 2010:

- Tipping fees for disposal facilities were projected from 2003 to 2010 using the CPI, San Francisco-Oakland-San Jose, for the disposal facilities in the San Francisco region and the CPI, Los Angeles-Riverside-Orange, for the disposal facilities in the Greater Los Angeles region, except as follows:

  a.) For disposal facilities with approved or stated contractual tipping fees or that had defined methodologies for calculating the tipping fees, the approved or contractual tipping fees or the fees calculated using the defined methodologies were used.

  b.) In Los Angeles County, it was assumed that disposal facilities without approved or stated contractual tipping fees or defined methodologies to calculate tipping fees would increase at the same dollar amount per year as the Puente Hills Landfill ($2 increase per ton per year).

Contractual tipping fees, defined as the fees charged to large customers and client cities or the internal company rate at private landfills, were assumed to be 85 percent of the posted rate, unless the actual contractual rates were available. The contractual rate was not available for many of the private disposal facilities.

In the Greater Los Angeles region, 17 of the 29 landfills are owned and/or operated by county agencies. The dominance of the large, publicly owned landfills in the Greater Los Angeles region has stabilized landfill tipping fees over the years. Public facilities also tend to "levelize" tipping fees, charging the same tipping fees at each landfill within the system, regardless of the actual operating cost at each facility. For example, each of the three public landfills in the Orange County landfill system have the same tipping fee schedule, as do the public landfills in the Riverside County and San Bernardino County landfill systems.

Disposal Costs

We estimated the costs of disposal to compare to the costs of various conversion technology facilities. The CIWMB has a database of facilities and nominal tipping fees at landfills and transfer stations, which was updated for this study for facilities located in the two regions. The disposal costs consists of three tiers: 1) the posted gate rate, which is typically paid by customers that have lower volumes; 2) contract rates, which are paid by customers with larger volumes who have entered into contracts with facilities to deliver a certain quantity of waste, and 3) internal transfer prices for companies that own landfills (internal transfer prices are paid by the collection division of a company to that company's landfill division). If we had simply used posted tipping fees or gate rates, we would have overstated the disposal prices that most customers pay, and thus, misstated the comparative prices between disposal and conversion technologies.

We sought to estimate actual disposal prices that all customers pay. Many of the landfills in the two study regions are publicly owned and operated; therefore, the prices paid and the names of customers are a matter of public record. For example, the actual tipping fees are known (through public records) for more than two-thirds of the waste disposal in the Greater Los Angeles region. These public rates were verified through telephone surveys, web searches for posted rates, examination of publicly available contracts, and information from internal files on tipping fees proposed to jurisdictions during the procurement process.

Actual tipping fees were entered into the financial model. Assumptions were made in order to estimate the disposal prices paid when those prices could not be directly obtained through the records. In the absence of other information, the most likely assumption was that the actual tipping fee paid is the non-discounted, posted gate rate. We constructed Table 31 and Table 32 to summarize the number of tons disposed in each study area at a range of disposal prices, as of December 2003. Projections of tons and prices for 2010 are also included in these tables.

Table 31. Projected Tonnage by Tipping Fee Range for the San Francisco Bay Region (December 2003)

Tip Fee Per Ton	Tons Per Year - 2003	Percent of Total	Tons Per Year - 2010	Percent of Total
$0 to $10.00	-	0%	-	0%
$10.01 to 20.00	-	0%	-	0%
$20.01 to $30.00	1,525,456	22%	338,239	4%
$30.01 to $40.00	1,143,176	16%	1,359,866	18%
$40.01 to $50.00	2,459,491	35%	864,700	11%
$50.01 to $60.00	1,449,859	21%	2,794,412	37%
$60.01 to $70.00	361,682	5%	686,851	9%
$70.01 to $80.00	-	0%	1,183,994	16%
$80.01 to $90.00	-	0%	348,407	5%
Total	6,939,664	100%	7,576,469	100%

Table 32. Projected Tonnage by Tipping Fee Range for the Greater Los Angeles Region (December 2003)

Tip Fee Per Ton	Tons Per Year - 2003	Percent of Total	Tons Per Year - 2010	Percent of Total
$0 to $10.00	-	0%	-	0%
$10.01 to 20.00	1,171,707	6%	-	0%
$20.01 to $30.00	11,193,242	62%	5,589,295	28%
$30.01 to $40.00	4,759,395	26%	8,726,399	44%
$40.01 to $50.00	627,824	3%	3,009,216	15%
$50.01 to $60.00	376,234	2%	2,312,633	11%
$60.01 to $70.00	-	0%	399,713	2%
Total	18,128,402	100%	20,037,256	100%

For the years 2004 through 2010, we estimated the tipping fees. In some cases, there are countywide long-term contracts, which either specify fixed prices or contain inflation-based escalators. In the Greater Los Angeles region, for example, all of the Orange County landfills are governed by long-term contracts with their customers that specify prices beyond 2010. Similarly, the majority of the refuse tonnage entering the County of San Bernardino disposal system comes in under long-term contracts, with 16 of the county's 24 cities having waste disposal agreements. Also, the county system's contract operator has contracted to bring in a large percentage of the system's tonnage.

Limitations of Disposal Projections

Our projections of the landfill tipping fees and tonnage were based on certain assumptions, as described above. The actual results will usually differ from projections because events and circumstances frequently do not occur as expected, and the difference may be significant. These tonnage and price projections do not include the effects of planned diversion programs, which are documented in the next section of this chapter, Feedstock Composition, because we do not know which price segment of the waste stream will be affected. In many cases, these projections do not show the effects of transfer stations and transfer station pricing on the customers. When a landfill closes, waste in that area may be redirected to a local transfer station before being transferred to a more distant landfill. Customers taking waste to a transfer station will pay the higher rate for both transfer and disposal.

Material Recovery Facility Residuals

Currently, there is permitted capacity at materials recovery facilities for at least 10,113,303 annual tons in the Greater Los Angeles region, and for at least 2,809,703 tons in the San Francisco Bay region. This is based upon information combined from the MRF Yearbook and the SWIS database. However, facility operators use only a small percentage of this capacity for sorting recyclables. Many facilities use much of their capacity to transfer material to landfills without processing.

MRF residuals are sufficient to supply the hypothetical configuration of conversion technology facilities in the Greater Los Angeles region throughout the study period of 2003 to 2010. In the San Francisco Bay region, MRF residuals could comprise slightly more than half of hypothetical conversion technology demand. Residuals from "clean" MRFs, which receive and sort cleaner loads of recyclables such as recyclables from residential curbside collection programs, amount to under 100,000 tons per year in each of the two regions. Capacities of mixed waste processing facilities amount to more than 600,000 tons per year in the San Francisco Bay region and over 6 million tons per year in the Greater Los Angeles region. However, those nominal capacities are for the overall facilities, which usually contain a smaller sorting component attached to a larger transferring component.

Feedstock Composition

The likely feedstock for conversion technology facilities is comprised of materials otherwise destined to be landfilled (refuse and MRF residuals), with certain exceptions as noted in Chapter Six. This feedstock requires specialized sorting prior to being used in any of the conversion technology processes. Each of the three technologies (acid hydrolysis, gasification, and catalytic cracking) have different, specific requirements for their feedstock and different materials required to be removed. This pre-sorting can produce additional diversion of recoverable materials, as well as separate out refuse that must be directed to the landfill. In order to estimate possible additional diversion and disposal, we must first know the composition of the waste stream.

The CIWMB provided us with the current composition of the waste stream by region (Greater Los Angeles and San Francisco Bay regions). These data originated from the CIWMB's waste characterization database; however, these waste compositions will change over time as diversion programs are implemented and specific materials are removed from the waste stream. Therefore, we estimated additional diversion and its effects on the composition of the waste stream.

Change in Feedstock Composition Due to New Recycling Programs

Many jurisdictions in California have yet to fully comply with the diversion rate goals of the IWMA. The San Francisco Bay region has 82 jurisdictions. The number of jurisdictions in the San Francisco Bay region that had not yet reached 50 percent diversion was 44 in 2001 and 50 in 2002, the most recent year for which diversion results are available. The were 105 jurisdictions in the Greater Los Angeles region that had not yet reached 50 percent diversion in 2001 and 106 in 2002, out of 171 jurisdictions in the area. These diversion estimates are preliminary default rates calculated by the CIWMB's Diversion Rate Calculator and do not reflect additional documentation that may have been provided by the jurisdictions to improve their diversion rates.

Some of these jurisdictions with less than 50 percent diversion rates will be able to show compliance with the IWMA through a good faith effort finding by the CIWMB, but the majority of these jurisdictions have already asked for, and received, a time extension. Some others are under compliance orders from the CIWMB and must implement new programs to divert additional materials or face penalties.

The time-extension application prepared by a jurisdiction explains the programs it will implement in order to increase the diversion rate to 50 percent and estimates a tonnage recovery amount for each program. The CIWMB provided us with a list of these programs from its progress tracker database (SB 1066 Electronic Program Implementation Status Report: Guidelines for Jurisdictions). We have also extracted program data and tonnage estimates from the time extension applications. In the cases where the data was not material-specific, we estimated the quantities of new plastics, paper, and green waste the jurisdictions are pledging to recover, using average recovery rates (from programs implemented in other jurisdictions) for the types of programs specified. We used the method described below to adjust the waste composition accordingly.

Waste Composition Estimates for Various Diversion Programs

The CIWMB provided copies of SB 1066 time-extension applications. Program descriptions were used to estimate the percentage of anticipated tons diverted as paper, plastic, organics, source reduction of organics, or other material. The anticipated tons to be diverted by each project were multiplied by the waste composition percentages specific to that type of program to determine how many tons of each material would be diverted.

The diversion percentages used for residential recycling programs were based upon data received from a waste hauler and a MRF operator. The MRF operator provided a spreadsheet showing actual tons of material received at their facility from eight cities over a one-year period. The total tons of materials from all cities were added together to determine the overall weighted average composition of a typical residential curbside collection program.

From data in our files, we obtained a standard composition for MRFs for mixed waste processing of commercial waste for a city that sends all of its commercial waste to a MRF. The data included the number of tons of each material type recovered from the waste stream sent to the MRF. The percentage breakdown was verified as typical by an industry expert.

Diversion waste composition estimates for source-separated commercial recycling programs were obtained by examining the audit reports from recyclers that were audited as part of a city's new base year study for 2000. Each material type was calculated as a percentage of the entire amount diverted.

Categorizing SB 1066 Program Tons into Material Types by Year

After all programs were broken down into their material components, the programs were classified by year of implementation. Because we started with disposal totals for 2002, we disregarded programs with implementation dates prior to 12/31/02. Programs required to be implemented by 12/31/02 to 12/30/03 were grouped as 2003 programs. Programs required to be implemented by 12/31/03 to 12/31/04 were categorized as 2004 programs. By year and by region (San Francisco and Los Angeles), the programs were grouped and the tons in each category were added.

Adjustment to Waste Composition

Our goal was to estimate the composition of the waste stream in each region through the year 2010, after adjusting for changes caused by new diversion programs implemented in accordance with SB 1066 extension applications. The resulting waste composition estimates were used to calculate the quantity of recyclables that would be removed from mixed waste in conversion technology feedstock preparation, as well as the amount of waste that would be suitable for processing by each technology. These waste composition estimates were also of primary importance to the life cycle inventory.

We obtained year 2002 tonnage generated within each region from the CIWMB's website page, Jurisdiction Disposal by Facility. The composition of the waste stream was estimated using 2000 data for the two regions obtained from the CIWMB's Waste Analysis Branch. These waste composition data are the most recent data available for these regions. Between 2000 and 2003, recycling programs and recycling tonnages increased, and other changes to waste stream composition may have occurred as well. The year 2003 waste compositions for the two regions are almost certainly different, and those differences may affect some of the estimates in this report.

Our projected increase in overall tonnage each year is based upon the projected population increases by region, as estimated by the California Department of Finance. The following steps were used to calculate waste compositions for each year of the study period (2003 to 2010):

1. From 2002 to 2003, increased all materials in the waste stream by the same percentage, and did not vary the overall composition.
2. Subtracted tonnage anticipated to be removed from the waste stream (through new diversion programs) in the year 2003 by material type, from the projected year 2003 tonnage.
3. Recalculated the new ratios between materials in the waste stream, based on the new tonnage total to calculate the new waste composition table.
4. Increased the final estimated year 2003 total tonnage by the estimated population growth rate to determine the year 2004 starting tonnage estimate.
5. Applied the newly calculated ratio between material types to the total to determine the tonnage for each material type.
6. Repeated these same procedures to remove materials to be diverted from programs to be implemented in 2004. Beginning with 2005, the waste composition remained consistent and tonnage was only adjusted by the projected population increase.

Preparing Feedstock for Use in Conversion Technologies

Feedstock methodology

The jurisdictions that have expressed an interest in conversion technologies have diversion rates of nearly 50 percent, or in some cases, above 50 percent. Several of the jurisdictions that have expressed an interest in conversion technologies have also emphasized that they plan to continue and expand on existing diversion programs and intend to send only the portion of waste that is currently being landfilled to a conversion technology facility.

In written surveys, facility proponents generally indicated that they would accept mixed waste materials and could clean the materials to their specifications. Mixed waste is the generally assumed feedstock for this report, but it should be noted that there are many different types of proposed conversion technology technologies, and each technology has different feedstock requirements.

Acid Hydrolysis Feedstock Composition and Preparation Requirements

According to facility proponents, acid hydrolysis can accept mixed waste for processing. In this context, mixed waste includes residuals from MRFs and waste normally sent to landfills. To prepare the waste for processing, certain materials must be removed for disposal or redirected to other facilities. Certain recyclables must be removed and can be recycled, with the remaining materials suitable for processing.

Certain loads, such as those containing construction and demolition debris or hazardous waste, are redirected to other facilities. Loads received are sorted to remove plastic, glass, and metal. Residuals from MRFs are not sorted in the same manner as needed for conversion technology, so any refuse, including MRF residuals, must be separately sorted prior to use at a conversion technology facility.

Plastics. Sorting at a typical MRF focuses on removing only the plastics for which there are markets and which are easily removed. For use in an efficient acid hydrolysis process, the feedstock should be from all plastics, particularly polyvinyl chlorides (PVC), which are not typically removed at MRFs. This required additional removal of plastics from the waste stream will generate a small amount of additional recycling. For the purpose of this study, we estimated that 50 percent of the additional plastic recovered could be recycled, 45 percent would be unmarketable, and 5 percent would be too difficult to remove and would turn into residual as it passes through the process.

Glass, Metal. All glass and metal are to be removed, assuming that 75 percent of the additional material would be recyclable, 20 percent would be unmarketable, and 5 percent would be too difficult to remove and would turn into residual as it passes through the process.

Paper, Organics, Mixed Residue. Paper, organics, and mixed residue are the remaining desirable components of the acid hydrolysis feedstock and would enter the conversion technology for processing.

As a result, acid hydrolysis can process 61 to 64 percent of the incoming waste stream, recycle 12 to 13 percent of the incoming waste stream, and must dispose of the remaining 23 to 26 percent of the waste stream (see Table 33).

Table 33. Acid Hydrolysis Materials Disposition

Material Types	Disposition	Percentage of Waste Stream in the Greater Los Angeles Region	Percentage of Waste Stream in the San Francisco Bay Region
Paper, organics, and mixed residue	Processed by acid hydrolysis	65%	61%
Portions of plastics, glass, and metals that can be recycled	Recycled	12%	13%
Construction and demolition debris, household hazardous waste, special waste, and the portion of the plastics, glass, and metal waste streams that cannot be recycled	Disposed	23%	26%

Gasification Feedstock Composition and Preparation Requirements

According to facility proponents, gasification can accept MSW for processing. In this context, mixed waste includes residuals from MRFs and waste normally sent to landfills. To prepare the waste for efficient processing, certain materials should be removed for disposal or redirected to other facilities. Metals, glass, and other recyclables should be removed and can be recycled. The remaining materials are suitable for processing.

Gasification feedstock is sorted in the same manner as described above for acid hydrolysis, except that plastic is not removed.

Construction and Demolition Debris, Hazardous Waste. Gasification facilities direct loads containing construction and demolition debris or hazardous waste to other facilities, similar to acid hydrolysis facilities.

Glass, Metal. Glass and metals are removed during sorting, with the assumption of recycling 50 percent of the material removed from the feedstock, and disposing of the remaining non-recyclable materials.

Paper, Plastic, Organics, Mixed Waste. These remaining materials, much of which would typically be removed from the waste stream during sorting, are not be removed during pre-sorting for use in gasification.

As a result, gasification can process 69 to 74 percent of the incoming waste stream, recycle 8 percent of the incoming waste stream, and must dispose of the remaining 18 to 23 percent of the waste stream (see Table 34).

Table 34. Gasification Materials Disposition

Material Types	Disposition	Percentage of Waste Stream in the Greater Los Angeles Area	Percentage of Waste Stream in the San Francisco Bay Area
Paper, plastics, organics and mixed residue	Processed by gasification	74%	69.2%
Portion of glass and metals that can be recycled	Recycled	7.5%	8.1%
Construction and demolition debris, household hazardous waste, special waste, and the portion of the glass and metal waste streams that cannot be recycled	Disposed	18.5%	22.4%

Catalytic Cracking Feedstock Composition and Preparation Requirements

Unlike the other technologies studied that may accept a variety of materials with specific troublesome materials sorted out, catalytic cracking processes only plastics. Using specific information supplied by one vendor, initially the process will require only film plastics; however, because the process can accept various types of plastics, other types may be added in the future as opportunities present themselves.

MRFs and even acid hydrolysis presorting facilities can provide feedstock for catalytic cracking facilities by removing film plastic from the sorting lines. This plastic is difficult to market and recycle and typically ends in up landfills. By adding another sorting employee to a line to pull this specific type of plastic, this material can be redirected from landfilling to the conversion technology facility. Other sources of film plastics are source-separated film plastics from businesses and agricultural film. Table 35 shows the maximum film plastic tonnage available in each region.

Table 35. Film Plastic in Landfill-Bound Waste Stream

Region	% of Waste Stream	2003 Tonnage
Greater Los Angeles	4.4%	800,000
San Francisco Bay	3.6%	250,000

Existing Institutional Relationships

Jurisdictions in California have the legal authority to mandate that solid waste be collected in a certain manner. They also have the legal authority to either provide collection services exclusively through a municipal department or to contract with a company for collection and disposal services. As a result, most municipalities have adopted a combination of the following approaches for collection and disposal of solid waste:

- Services are provided by a local jurisdiction, using its own employees and equipment.
- Services are provided by a single exclusive hauler, under contract to the jurisdiction.

- Non-exclusive rights are granted to a list of haulers, that either operate competitively or in certain pre-determined zones, and/or, the jurisdiction does not make any restrictions. Any hauler is free to provide services, and haulers make arrangements directly with the customers they serve.

Nearly all of the jurisdictions in both study regions were surveyed to estimate the percentage of population in each region that were served by each of the approaches listed above.

We determined that some jurisdictions have separate agreements for collection and landfill disposal in the San Francisco Bay region. However, very few jurisdictions in either region exercise direct control over specific recycling or composting facility arrangements. In general, the collection contracts usually specify that recycling and composting must be accomplished but do not specify facilities or prices.

According to the survey data collected for this study, in the Greater Los Angeles region, approximately 42 percent of residential waste is hauled by municipally owned and operated collection vehicles, 54 percent is hauled by private companies under contract with the city, and the remaining 4 percent is hauled by a variety of private companies who contract directly with residents.

In the San Francisco Bay region, approximately 3 percent of residential waste is hauled by municipally owned and operated collection vehicles, 81 percent is hauled by private companies under contract with the city, and the remaining 17 percent is hauled by a variety of private companies who contract directly with residents.

The commercial sector waste is less regulated than the residential sector in the Greater Los Angeles region. Four percent of the waste is being collected municipally; 48 percent, through contracts with waste haulers, and the remaining 48 percent is open to competition from multiple haulers. In the San Francisco Bay region, nearly all of the commercial waste is hauled by contract haulers that have exclusive rights to collect the waste.

In both regions, landfills, MRFs, and organics-processing sites are owned and operated by a combination of government agencies and the private sector.

Jurisdictions Interested in Conversion Technology

Several jurisdictions and one public utility in California have expressed interest in conversion technology and have pursued various studies and projects to explore their possibilities.

City of Los Angeles

The City of Los Angeles approved a contract with the URS Corporation to study conversion technologies.

County of Los Angeles

The recently formed subcommittee, the Alternative Technology Advisory Subcommittee to the Los Angeles County Solid Waste Management Committee Integrated Waste Management Task Force, developed a scope of work and issued an RFP for a study to investigate and determine the best landfill alternatives for the county. The subcommittee reviewed all the proposals and selected the URS Corporation to conduct the tasks listed in the scope of work.

This subcommittee and project are funded by contributions from the Los Angeles County Sanitation Districts, which are required under the District's Puente Hills Landfill Conditional Use Permit (CUP). The CUP requires that the permittee contribute to the county up to $100,000 per year, to a maximum of $1,000,000, toward the cost of studies alternative disposal technologies that may be most appropriate for Southern California from an environmental and economic perspective, as well as the cost of promoting and implementing such technologies. Los Angeles County staff is in the process of selecting a consultant to begin such work. If the study identifies one or more technologies that the permittee and the County Director of Public Works determine to be viable, the permittee may be required to provide additional funding to develop the technologies on a pilot scale.

Several other jurisdictions are working on conversion technology studies, and those efforts are discussed in the following section.

Conversion Technology Pricing Assumptions

Methodology—Identification of Sources

Five sources were consulted in order to estimate the per ton cost, or tipping fee, to haulers to deliver MSW to each of the three conversion technologies addressed in this study. These data sources are the following:

- The survey of conversion technology proponents conducted by the University of California at Davis and Riverside, 2003, as well as follow-up phone calls with prospective facility vendors.
- National Renewable Energy Laboratory's (NREL's) independent conversion technology facility cost estimates.
- Santa Barbara County Multi-Jurisdictional Solid Waste Task Group and its *Alternatives to Disposal Final Report,* September 22, 2003.
- Contracts between the City of Middletown, New York, and Pencor-Masada OxyNol's Orange Recycling and Ethanol Production Facility.
- Alameda Power and Telecom.

Descriptions of Data Sources

University of California at Riverside and Davis Survey

UCR and UCD conducted a study of 12 conversion technology proponents, collecting data in the form of a survey. The seven-page questionnaire requested information as to the commercial status of the technology, the type of feedstock, the products to be generated, the patents and licenses held, and the fee charged for feedstock. Survey respondents were unable to provide an estimate of the amount to be charged to accept feedstock, because none of these facility proponents had a facility operating in the country yet. All facility proponents said that tipping fees would be dependent on location and other local conditions.

NREL Estimates

Using the results of the conversion technology proponents' survey, as well as patent documents and other information, NREL independently estimated capital and operating costs for the three conversion technologies discussed in this study.

Santa Barbara County

The Santa Barbara County Multi-Jurisdictional Solid Waste Task Group formed an Alternatives to Disposal subgroup to study the issue of conversion technologies and other issues. The subgroup recommended that a waste conversion facility be considered as a superior long-term alternative to landfilling. In response to the subgroup's recommendation, the Solid Waste Task

Group prepared a study to determine if a conversion technology facility has a place in the future of the Santa Barbara County region's solid waste system. The task group conducted an RFI sending questionnaires to 51 vendors worldwide. The majority of vendors worked with gasification, hydrolysis, and anaerobic digestion. The RFI requested estimates in several revenue, capital cost, and operating cost categories, and the task group used those cost estimates to compute an average cost per ton for each technology.

Based on the task group's calculations, the average net cost per ton for all technologies based on all companies responding was $23 per ton. The net cost for the highest ranking of the proposals was $15.54 for a gasification facility proposal. Due to confidentiality issues, we were unable to obtain additional supporting data for these costs. These costs appear to exclude profit and state, host, or local fees, and other fees. The process was an RFI, not an RFP, so it is not known what tipping fees the facility vendors might offer under actual proposal circumstances.

Pencor-Masada OxyNol (Masada) Contract with Middletown, New York

Masada has contracted with the City of Middletown, New York, to build and operate a waste-to-ethanol plant in the city for 20 years, plus possible extensions of 5 to 15 years. We have reviewed the contracts between the city and Masada, as well as press releases and news articles regarding the facility. The Masada facility, named The Orange Recycling and Ethanol Production Facility, plans to accept and process MSW, including white goods, but excluding tires, construction and demolition debris, and hazardous waste. The waste received will be sorted to recover recyclables such as glass, metal, and plastic. Paper is not addressed, and we assume that the facility intends to process paper rather than remove it. The facility also accepts and processes sludge (biosolids). Masada expects to divert approximately 90 percent of waste material it receives.

The facility is permitted for 800 tpd. It will be open to accept waste Monday through Saturday, with the contract assuming 286 operating days per year. Masada will contract with jurisdictions in neighboring counties, as well as the City of Middletown. The standard contract requires that customers deliver a minimum number of tons, but no more than 108 percent of that agreed upon minimum. Delivery of tonnage above 108 percent or below 100 percent will result in additional fees charged to the customer (the cities).

The City of Middletown has committed to delivering 13,000 tons of MSW and 3,000 tons of sludge (biosolids) per year and has the ability to accept other feedstocks as well (for example, agricultural and wood wastes). Fifteen other jurisdictions are anticipated to sign similar agreements. If all contracts are signed, the facility would be operating at capacity. If the jurisdictions cannot deliver waste to the conversion technology facility due lack of development of capacity by Masada, then Masada will pay the additional cost to bring the material to another facility.

Masada will initially charge the City of Middletown a tipping fee of $65 per ton for MSW and $22.50 to $80 per ton of sludge (depending upon solids content), but no more than the lowest tipping fee contracted for with other jurisdictions. These tipping fees include revenue to cover a number of significant city fees, including a one-time payment, of $50,000, a base host fee of $1 million per year (adjusted for inflation), an additional host fee of $3.64 per ton of waste accepted (adjusted for inflation), $100,000 per year in city salary reimbursements, and starting on the contract's third anniversary, a $100,000 payment in lieu of local taxes. The tipping fees and disposal facilities in the area are currently $75 per ton of MSW and $65 for ton of sludge.

The City of Middletown Industrial Development Agency will own the facility, financed with tax-exempt bonds, and lease it to Masada for $100,000, payable at closing, plus $100 per year.

A true comparison of the tipping fees necessary to operate a facility would require a determinination of Masada's tipping fee net of the above listed fees paid to the City of Middletown. A comparable tipping fee in California would also be lower because California's landfill tip fees are lower. The tipping fee must include funds to send residuals (approximately 10 percent of the material) to a landfill.

Alameda Power and Telecom

Alameda Power and Telecom (Alameda P&T) anticipates increased electricity needs and is seeking a renewable resource located near the City of Alameda to supply between 12 and 20 MW of additional base load generation. Approximately 80 percent of its power supply is already renewable. Having identified pyrolysis and gasification as technologies that would meet its needs, the agency issued a "Request for Qualifications to Power Generation Utilizing Pyrolysis/Gasification of Municipal Solid Waste" on April 2, 2003. Thirteen companies have submitted qualifications, and Alameda has the proposals under review.

No tipping fee information was available from this process at the time of our data collection.

Riverside County

The County of Riverside is closing the Edom Hill Landfill this year and has entered into a lease with Waste Management of the Desert to build and operate a new transfer station on the site. As part of the lease agreement, Waste Management and the County of Riverside were required to investigate conversion projects for implementation on a site adjoining the new transfer station. An RFI and solicitation of Statements for Qualifications was issued. The County of Riverside received 15 proposals, which they narrowed down to 4 finalists, with a final decision pending.

Facility Costs

Based on the limited information available, conversion technology facilities are anticipated to require a large capital investment, ranging from $40 million to $70 million for a facility that can process 500 to 1,000 tpd. In order to secure financing, the facilities will likely require contractual commitments from municipalities or haulers to secure the waste streams that will supply the facilities.

The Masada plant that is to be built in Middletown, New York, has put-or-pay contracts with local jurisdictions that require a tight range of waste quantities to be delivered to the facility, from 100 percent to 108 percent of the amount committed to in the contract. The plant will institute monetary penalties for too little or too much waste delivered. The length of the contract is 20 years.

Conversion Technology Pricing and Contractual Arrangements

Facility proponents have offered prices as low as $25 per ton and as high as $65 per ton for the signed contract in Middletown, New York, as estimated in the Santa Barbara County RFI process. In addition to the capital and annual operating costs of the facilities, local landfill prices affect costs. With the acid hydrolysis process in New York, 10 percent of the waste emerges as residue and must be disposed of in a landfill at the local rate of $75 per ton, which equates to $7.50 of the $65 per ton processing fee. Host fees (in lieu of business license fees for the host jurisdiction) affect overall cost; host fees are nearly $8 per ton for the facility at Middletown, New York.

Job and Revenue Conversion Factors

To estimate job and revenue impacts from various changes in recycling, composting, and landfilling, we primarily used *U.S. Recycling Economic Information Study* that was prepared for the CIWMB by R.W. Beck in June 2001. That study provided the following estimates:

- Total number of businesses and jobs related to recycling and other diversion activities in California.
- Total revenues related to recycling and composting.
- Estimated number of jobs created per thousand tons diverted.
- Economic impact by material type (that is, paper, plastics).

Another source of data was a press release by Masada that stated that the conversion technology facility will create 200 jobs for the region, in addition to the 350 to 800 temporary construction jobs created during development.

Table 36. Jobs and Revenues Conversion Factors

Material	Tons	Revenue (in $1'000s)	Jobs	Revenue/ Ton ($)	Jobs/1,000 Tons
Landfills[a]				Tip fee	0.67
CT[b]				Tip fee	0.8
MRF[c]	3,625,000	206,424	2,606	56.94	0.72
Paper[c]	2,515,000	1,216,846	3,460	483.84	1.38
Plastic[c]	234,000	2,602,773	18,045	1,122.96	77.12
Organics[c]	9,208,000	304,722	1,892	33.09	0.21
Glass[c]	744,000	704,522	3,710	946.94	4.99
Metals[c]	1,543,000	2,182,616	12,863	1,414.53	8.34
Weighted "Other"	2,287,000	2,887,138	16,573	1,262.41	7.25

[a] Based upon Platt and Morris (1993), as cited within *The Economic Impact of Waste Disposal and Diversion in California*, George Goldman and Aya Ogishi, April 4, 2001.

[b] Conversion technology job info based upon Masada contract and press releases.

[c] Based upon data from the *U.S. Recycling Economic Information Study* R.W. Beck, July 2001.

Note: Weighted "Other" is just Metals and Glass.

ANALYSIS OF KEY BACKGROUND DATA

Facility Location Assumptions

The study used three assumptions regarding the location of these potential conversion technology facilities. The first assumption, described in the facility configuration scenarios, is that the first facilities to be developed would be developed in the two major population centers in the state: the San Francisco Bay region and the Greater Los Angeles region. The second assumption is that conversion technology facilities would be co-located at landfills or MRFs. The third assumption is that these conversion technology facilities would be geographically dispersed throughout each of the two regions under the study, and that differences in transportation costs to either recycling or conversion technology facilities are assumed to be insignificant to the study findings.

Regarding co-location, if conversion technologies are co-located with the MRFs that conduct the preprocessing function, then there will be no transportation costs between the preprocessing function and the conversion technology. This assumption is constant throughout the analysis, whether a smaller conversion technology operation co-locates with an existing MRF, or whether a larger conversion technology is built with its own preprocessing function attached. If a conversion technology is co-located with a landfill, then transportation costs would be the same to direct haul refuse to the landfill or conversion technology facilities.

Development costs for conversion technology facilities may be large and will have a dominant impact on facility economics.

The independent estimates of development costs produced by NREL indicate that an 823 ton-per-day facility could cost approximately $70 million to build, including land acquisition, equipment costs, site engineering, and permitting. (Total incoming material is 823 tons; after sorting, approximately 70 to 75 percent of the material will enter the conversion technology process.) Included in that cost estimate is sufficient MRF equipment to achieve the sorting necessary to prepare the feedstock.

A facility of this size could receive the waste from a service area with a population of approximately 250,000, assuming average-per-capita waste generation rates. On a per-ton basis, these costs are on the order of cost estimates received by the County of Santa Barbara. Costs vary based on the size of the facility and the extent of MRF-type sorting equipment included on-site. The debt service on such a facility (assuming a 20-year term and 20-year equipment life) would equate to $21 to $31 per ton for interest rates of 5 percent and 10 percent, respectively.

Landfill Costs for Residuals

If the facilities have a 10 percent residual rate, and landfill fees range from $25 to $45 per ton, then costs for landfilling residuals will equate to $2.50 to $4.50 per incoming ton, plus transportation costs of $8 to $10 per ton, on average. The 10 percent residual rate was used for this analysis because conversion technology developers generally estimated that 10 percent of facility throughput would require landfill disposal.

Operating Revenues and Costs

Operating costs and operating revenues from the sale of chemical products, fuel products, recyclables, and energy will vary between the different technologies and are very speculative. However, it is clear that operating margins (excess revenues after paying all costs of operations) must be large enough to pay for both debt service and landfilling of residuals before any profits can be realized. In addition, certain fuel products, energy, and recyclables have very volatile prices.

Conversion Technology Pricing and Contractual Arrangements

The debt service described above creates an imperative to receive guaranteed quantities of material that pay a tipping fee to deliver waste to a facility, unless the facility has an operating margin sufficient to cover debt service. Mixed waste destined for landfilling is currently the feedstock that pays the highest prices for delivery to facilities, followed by green waste. In certain regions, green waste tipping fees and landfill tipping fees are only a few dollars apart. In other regions, green waste can be delivered for use as ADC at a substantial discount (between $10 and $20 per ton).

Economics of Common Material Recovery Facility Processing

Currently, MRF development in California has been driven largely by the diversion goals set by the IWMA. “Clean” MRFs process separated and commingled recyclables, and “dirty” MRFs remove recyclables from mixed waste.

For clean MRFs, many different contractual arrangements exist between jurisdictions and the MRFs that are used to sort their recyclables. Each jurisdiction makes its own arrangements with respect to sharing the revenues from the sale of recyclables. In jurisdictions where the hauler keeps all of the recycling revenues, the overall price of collection may be lower than in jurisdictions where the hauler shares revenues with the jurisdiction.

With so many different arrangements, estimating the costs of sorting versus the value of recycling revenues can be difficult. Within our internal records of such contracts, we identified a few cases of MRF agreements that separate MRF sorting and processing costs from the sale of recyclables. These facilities typically charge customers approximately $30 to $40 per ton for sorting and processing and typically recover 85 percent to 90 percent of the materials processed. Revenues from the sale of recyclables vary, but under current market conditions, they are typically $10 to $35 per ton after deducting for sorting, processing, and residual disposal costs.

Dirty MRFs typically recover 20 percent to 50 percent of the waste stream, and recyclable material sales do not generate sufficient revenue to pay for operating costs, transfer, transportation, and residual disposal of non-recoverable quantities. Dirty MRFs in the Los Angeles area typically charge $30 to $45 per ton to accept mixed waste.

Dirty MRFs make agreements with municipalities or haulers to process a certain quantity of mixed waste and achieve a certain diversion rate. From the MRF's perspective, the goal of this effort is to remove a certain quantity of materials, and the MRF typically focuses on those materials that have the highest resale value. Bottles and cans (with both scrap value and deposit value) and various grades of paper are typically removed; therefore, the resulting MRF residuals would likely have lower paper, plastic, metal, and glass content than average waste going to a landfill. (As of this date, no waste composition statistics are available to verify this statement; however, the CIWMB is undertaking a MRF residual waste composition study later this year.)

Once MRFs have met their contractual obligations, they may choose to sort additional tonnage and typically do so when the sale of recyclables (and the resulting avoided disposal costs) generates more income than the cost of additional sorting.

Chapter 6 Market Impact Analysis & Findings

This chapter presents the analyses and findings in response to the study objectives and key questions. The chapter is organized as follows:

1. Findings regarding impacts on tonnage and pricing in the recycling and organics markets (Findings 1-8).
2. Findings regarding impacts on landfill markets (Finding 9).
3. Findings regarding institutional arrangements (Findings 10–13).
4. Discussion of policy issues to be addressed by the CIWMB related to diversion credit for conversion technology facilities (Finding 14).
5. Summary of model results (Findings 15–19). The tables of quantifiable results for each scenario appear at the end of this chapter. The more detailed tonnage estimates and economic model descriptions appear in Appendix F.
6. Limitations of results.

Findings Regarding Impacts on Recycling and Organics Markets

One of the primary study objectives was to estimate tonnage and pricing impacts on recycling and composting industries due to conversion technology facilities. Pricing and availability of suitable feedstock materials (for conversion technologies, landfilling, recycling, and green waste) are the basis for most of the findings presented herein. Findings 1 through 13 assume that the conversion technologies in this study would not receive diversion credit. This chapter also discusses findings in the absence of diversion credits for conversion technologies.

Overall, our findings for the 2003–2010 study period can be summarized as follows:

- Implementation of the three conversion technologies studied are likely to have a positive rather than negative impact on the amount of recycling occurring in California.
- The total impact of conversion technology implementation on recycling markets is likely to be quite small relative to other likely developments, such as continued growth in the export of recyclable materials to China.

We have therefore organized the discussion of findings regarding impacts on recycling and organics markets into the following three potential outcomes:

a. Results that might occur if the implementation of conversion technology produces <u>increases</u> in materials sent to traditional recycling and composting markets (Finding 1).

b. Results that might occur if the implementation of conversion technology produces <u>no changes</u> in materials sent to traditional recycling and composting markets (Findings 2–4).

c. Results that might occur if the implementation of conversion technology results in <u>decreases</u> in materials sent to traditional recycling and composting markets (Findings 5–8).

Finding #1: There is a projected net positive impact on glass, metal, and plastic recycling under the "base case" conversion technology scenarios in this study, which include three technologies in the assumed configurations described in Chapter Five.

For economic reasons, we estimate that the "base case" is the most likely scenario. The base case results from mixed waste being used as the primary feedstock to conversion technology facilities (whether from a MRF or from collection routes). The base case scenario assumes no changes in current recycling economics (that is, prices remain approximately the same and demand remains strong), as well as no changes in State law to allow diversion credit for conversion technologies.

Using mixed solid waste as feedstock, preprocessing results in removal of 7 to 8 percent of feedstock for recycling at gasification facilities and 12 to 13 percent of feedstock for recycling at acid hydrolysis facilities. The new recycling is related to conversion technology preprocessing operations. Certain materials, such as glass and metals, can reduce the efficiency of conversion technology operations and can improve the economics of the system if they are recovered and sold. Because organics will not be removed through sorting, the base case results in no increases or decreases to compost markets.

In addition, plastics recycling will increase if acid hydrolysis facilities are built because plastics must be removed prior to processing. Currently, only those plastics with positive economic values are typically recycled. In contrast, feedstock preparation for acid hydrolysis would seek to remove all plastics.

The recycling of additional materials that otherwise would have gone to landfills may have positive economic effects on local recycling industries. The quantities recovered, however, would not be large enough to have a price impact on local recycling industries. The calculations of tons recovered and the average number of jobs and revenues associated with those tons appear in the summary table for Scenario 1.

Finding #2: Implementation of any of the three selected technologies is not likely to increase or decrease the recycling of paper.

Although paper is an acceptable feedstock for acid hydrolysis and gasification, the recent values of baled paper make it unlikely that paper will be directed to a conversion technology facility. Paper markets have historically been very volatile, with high prices for a given year being twice that of low prices for that year. However, average annual paper prices have been above zero for a 10-year period for all paper grades and have risen to more than $100 per ton for some grades of paper. Acid hydrolysis and gasification projects will require a payment (a tipping fee) to accept materials, and that tipping fee will likely be in the range of prices charged at local landfills ($25 to $60 per ton).

Finding #3: In the cases where conversion technology facilities accept materials that currently have no recycling or composting markets, and there are no new recycling markets for those materials in the foreseeable future, conversion technology facilities will have no impact on recycling and composting markets.

For example, if catalytic cracking were to target mixed plastics, grades 4 through 7, it would likely have an insignificant impact on current recycling markets and no impact on composting markets. Many other materials currently have no viable markets, but they could technically undergo various conversion technology processes. The likelihood of this happening will depend on economics and local conditions. The sum of costs (for feedstock preparation, sorting, transportation, and conversion technology tipping fees) would have to be lower than the current alternatives in order to be a viable option.

Finding #4: The impact of recent Chinese demand is a far more dominant force on the paper and plastics markets than potential development of conversion technologies in California, even on the fairly large scale that was assumed for this study.

Exports of paper and plastics, particularly to China, have increased dramatically during the past five years. These exports are exerting upward pressure on prices in the paper and plastics markets and are providing an outlet for all of the paper and plastics that are collected. Paper exported from this country has grown significantly in recent years: by 77 percent from 1993 to 2002, or an average of 6.5 percent per year. Nationwide, 24 percent of the paper recovered in the United States is exported for recycling.

Locally, exports from the Greater Los Angeles region increased 12.1 percent per year on average from 1998 to 2002, and exports from the San Francisco Bay region increased an average of 13.8 percent per year from 1998 to 2002. China has been the dominant driver of these increases in paper exports. During the 5-year period from 1998 to 2002, exports to China from these two California port areas have increased by 209 percent and represent 48 percent of the total exports for this period.

The growth figures cited above are for the sum of the most common grades of recycled paper. Different paper grades have grown at different levels. In particular, most of the recent growth has been in the area of mixed paper. Mixed paper previously had a value that was too low for economic recovery, but now it is priced high enough to make its recovery profitable.

Although available plastics statistics are not as detailed as those available for paper, recent news articles and discussions with plastics recyclers indicate that Chinese demand for recycled plastics has led to upward price pressure, in some cases leading to a doubling of prices. In the case of PET only, the increased demand for material is accompanied by stagnant levels of PET collection nationwide, which has caused material shortages for U.S. PET recyclers. Statistics from the National Association for PET Container Resources (NAPCOR) indicate that exports of PET increased 50 percent from 1999 to 2002 and now absorb 34 percent of all PET collected nationally.

Finding #5: Future recycling growth could be negatively impacted in three primary ways if recyclables were redirected to conversion technology facilities.

Future recycling growth could be negatively impacted in the following way if recyclables were redirected to conversion technology facilities:

a) If source-separated recyclables or green waste flowed to conversion technology facilities rather than recycling facilities.

b) If waste streams that are currently untapped for recycling became unavailable to new recycling efforts in the future.

c) If municipalities eliminated recycling and green waste collection programs and redirected mixed waste to conversion technology facilities.

These three outcomes are relatively unlikely, but we discuss them below. Model runs were not developed for these unlikely outcomes.

Item “c” is discussed in more detail later in this chapter, under the Policy Issues section.

Finding #6: Source-separated recyclables (paper and plastics) are not likely to flow to conversion technology facilities, based on pricing differentials.

Source-separated paper and plastics currently are recycled for profit. If this were no longer true and recycling market prices declined dramatically, conversion technology processes would still likely be more expensive than recycling. Furthermore, collection of source-separated recyclables would cease because collection would no longer be economical (revenues from sales of materials would not cover collection costs).

Exceptions to this finding would include conditions of extremely low recycling price swings, extremely low conversion technology tip fees (for example, caused by changes in technology or contracts), or the temporary collapse of export markets. All of these conditions are possible, but not foreseeable.

If catalytic cracking facilities are developed, and if those facilities target plastic bags, then jurisdictions might be encouraged to add plastic bags to their curbside recycling programs to be separated at a MRF for catalytic cracking feedstock. As a result of the convenience of placing materials in their curbside recycling bins, residents might stop returning plastic bags to grocery stores for recycling. This potential impact would be very small in terms of total tons redirected from existing recyclers to conversion technology.

Finding #7: Conversion technology facilities may negatively impact the ability of municipalities and private companies to increase recycling from currently untapped waste streams and generators, but the net affect of this is projected to be minimal.

The minimal impact is projected because many municipalities are already planning recycling growth in order to comply with IWMA mandates. (That growth is already accounted for in the waste composition projections discussed in Chapter Five and used in the financial and tonnage models.) Furthermore, the cost of tapping these waste streams is high, and private recyclers only have access to a small portion of the waste stream because municipalities control most of the waste stream, either directly or through exclusive contracts with waste haulers.

Extreme conditions that might change this finding include changes in the recycling markets (for example, higher prices and demand) or recycling technology (for example, automated sorting technologies), new commitments to recycle by waste generators as a result of legislation or product stewardship commitments, or through municipalities that might be attracted to conversion technology as part of municipal plans to maximize recycling and focus on "zero waste" strategies.

Finding #8: Source-separated green waste could conceivably flow to conversion technology facilities under certain circumstances. However, assuming no diversion credit is allowed for conversion technologies, significant quantities of green waste that are currently delivered to composters or to landfills as ADC will probably not be redirected to conversion technology facilities.

Significant quantities of green waste currently delivered to composters or to landfills as ADC will probably not be redirected to conversion technology facilities for the following reasons:

1. Currently, jurisdictions that contract for source-separated collection of green waste will continue to require their contractors to deliver green waste to facilities that qualify for diversion credit. Either public agencies or haulers under contract to public agencies deliver approximately 80 percent of the material to green waste diversion facilities.

2. Green waste delivered to diversion facilities at posted rates probably is delivered by self-haulers that are not regulated by contractual arrangements with public agencies. Approximately 20 percent of the green waste delivered to diversion facilities pay the posted rates. These self-haulers will deliver their green waste loads to the most economical facility. Currently, these self-haulers pay posted rates at green waste facilities

of $11 to $31 per ton in the Greater Los Angeles region and $15 to $40 in the San Francisco Bay region. It is unlikely that conversion technology prices will be competitive for most of this tonnage. Furthermore, conversion technology facilities will be most interested in steady waste flows from contract haulers rather than the uneven flow delivered in loads from self-haulers. If green waste is sent to conversion technology facilities based only on price, composting and mulching facilities are likely to be impacted more than facilities using green waste as ADC, because ADC prices are generally much lower.

3. Sufficient refuse tonnage is available to fully utilize the capacity of the assumed hypothetical conversion technology scenario that is more economic than separated green waste. As a result, conversion technology facilities, in order to maximize profit, are likely to charge tipping fees that are competitive with landfill costs. For 2003–04, a conversion technology tipping fee of $30 to $40 per ton in the Greater Los Angeles region and $40 to $50 per ton in the San Francisco Bay region should be able to attract sufficient refuse to be used as feedstock, and there would be no need to lower conversion technology prices to attract green waste.

The above assessment is contingent on a policy of not providing diversion credit for conversion technology facilities. If diversion credits were provided without regulatory measures to protect current feedstock, public agencies would have an economic incentive to discontinue separate green waste collection and instead deliver mixed loads of refuse and green waste to conversion technology facilities, because these facilities would likely be less costly as a result of savings in waste hauling costs. (This possibility is discussed in the section, Board Policy Issues Related to CT Diversion Credit.)

Alternatively, if local or regional composting markets collapse, perhaps as a result of increased air quality regulations or decreases in use of ADC, then conversion technology may be as attractive an outlet for these materials as landfills. Furthermore, for agricultural and wood wastes that are outside of the scope of this study, conversion technology might compete with biomass markets.

Findings Regarding Impacts on Landfill Markets

Finding #9: Based on the assumed configuration of conversion technology facilities that were chosen for evaluation in this study, conversion technology tonnage would represent about 7 percent of the landfill tonnage in the Greater Los Angeles region in 2003, increasing to 11 percent of the landfill tonnage in 2010. The exact same configuration of facilities would have a greater impact on the San Francisco Bay region landfill market, with conversion technology tonnage representing about 22 percent of the landfill tonnage in 2003 and rising to 33 percent in 2010.

The two areas studied—the nine-county San Francisco Bay region and the four-county Greater Los Angeles region—and the assumed number and size of conversion technology facilities were established as the hypothetical scenarios to be analyzed in the study. As material destined for landfills is the most feasible material to be directed to conversion technology facilities, we have compared the total feedstock demand for assumed conversion technology facilities to the projected waste to be directed to landfills if conversion technologies were not developed.

The hypothetical configuration used for this study amounts to approximately 1.4 million tons of waste being sent to various conversion technology facilities in each of two regions. Through growth in the number of facilities, the hypothetical annual tonnage requirement will rise to 2.2 million tons in 2010. In the San Francisco Bay region, approximately 6.5 million tons of waste were landfilled in 2002, and in the Greater Los Angeles region, approximately 19 million tons of waste were landfilled in 2002. After accounting for population growth and growth of diversion programs, estimated disposal for the San Francisco Bay region is approximately 6.7 million tons of waste for 2010, and 20 million tons in the Greater Los Angeles region in 2010.

Due to the relatively smaller size of the San Francisco Bay region, the development of conversion technologies would have a far more significant effect on landfills in this area than in the Greater Los Angeles region. Based on the assumed configuration of conversion technology facilities that were chosen for evaluation in this study, conversion technology tonnage would represent about 7 percent of the landfill tonnage in the Greater Los Angeles region in 2003, increasing to 11 percent of the landfill tonnage in 2010, as shown in Table 37. The exact same configuration of facilities would have a greater impact on the San Francisco Bay region landfill market, with conversion technology tonnage representing about 22 percent of the landfill tonnage in 2003 and rising to 33 percent in 2010 (Table 38).

Table 37. Conversion Technology Tonnage Estimates, Greater Los Angeles Region, 2003 and 2010

Conversion Technology Facilities	Hypothetical Tonnage, Los Angeles Region, 2003	Hypothetical Tonnage, Los Angeles Region, 2010
Acid Hydrolysis	630,176	1,048,766
Gasification	737,681	1,102,294
Catalytic Cracking	16,450	16,450
Total CT Tonnage	1,384,307	2,167,510
Total Landfill Tonnage	19,000,000	20,000,000
CT Tonnage, as a Percent of Landfill Tonnage	7%	11%

Table 38. Conversion Technology Tonnage Estimates, San Francisco Bay Region, 2003 and 2010

Conversion Technology Facilities	Hypothetical Tonnage, San Francisco Region, 2003	Hypothetical Tonnage, San Francisco Region, 2010
Acid Hydrolysis	641,780	1,072,542
Gasification	754,643	1,131,712
Catalytic Cracking	16,450	16,450
Total CT Tonnage	1,412,873	2,220,704
Total Landfill Tonnage	6,500,000	6,700,000
CT Tonnage, as a Percent of Landfill Tonnage	22%	33%

Findings Regarding Institutional Arrangements

Finding #10: Although conversion technology facilities may add innovative new options to existing integrated waste management schemes, they won't likely result in fundamental changes to existing institutional arrangements.

Ultimately, jurisdictions can control most of their waste streams and have the right to contract with others to handle the wastes generated within their boundaries. Most waste is collected and transported to landfills or diversion facilities by either waste haulers, jurisdictional agencies, or self-haulers. If they are developed, conversion technology facilities may exist as stand-alone facilities. More likely they will arrange to receive materials through contracts with jurisdictions, haulers, or both. In this way, conversion technology facilities will not change existing institutional arrangements. Rather, if they are developed, they will fit within the structure that already exists, augmenting the options that are currently available. Indeed, many conversion technology developers are seeking to obtain contracts with jurisdictions and waste haulers.

Finding #11: Assuming conversion technology is not eligible for diversion credit, most municipalities are not likely to shift from existing recycling programs to conversion technology contracts.

Most municipalities are slow to change their practices because integrated waste management systems are planned over a 5- to 10-year planning horizon, at a minimum. However, in some circumstances, municipalities will seek to contract with or own a conversion technology facility, perhaps as an alternative to landfilling.

Finding #12: Because conversion technology facilities require such large capital investments (ranging from $40 million to $70 million), the facilities will likely require contractual commitments from municipalities or haulers to secure the waste streams that will supply the facilities.

The facilities and their investors or lenders may require this guaranteed revenue stream before undertaking the financial risk. Smaller, modular facilities will experience similar debt service commitments when evaluated on a per ton basis.

Finding #13: A small but significant number of municipalities are interested in exploring conversion technology as an alternative to landfilling.

These municipalities appear to be attracted to the possibilities that conversion technologies offer, including creation of an alternate renewable energy source, reduction of waste to landfills (with or without diversion credit), and a more local facility alternative than distant regional landfills. For some, conversion technology facilities will offer financial benefits in areas where landfills are distant and/or have high tipping fees.

Another potential benefit is increased diversion from feedstock preprocessing, which can aid jurisdictions in meeting their IWMA goals.

Board Policy Issues Related to Conversion Technology Diversion Credit

A CIWMB policy on diversion credit for conversion technologies was established by a resolution that passed at the April 2002 Board meeting. The CIWMB's resolution contained four key paragraphs (excerpted below in Table 39), three of which set conditions for granting diversion credit to jurisdictions for wastes processed at a conversion technology facility. The policy was eventually superceded by the passage of Chapter 740, Statutes of 2002 (Matthews, AB 2770), but it is included here as an indication of the CIWMB's policy direction at the time and because it allows us to develop scenarios consistent with previously adopted policy in order to gauge what might happen in the future.

Table 39. Excerpted Paragraphs from Board Resolution 2002-177 (Revised and Adopted by the CIWMB)

Option 2B (Definition): “"Conversion" means the processing, through non-combustion thermal means, chemical means, or biological means, other than composting, of residual solid waste from which recyclable materials have been substantially diverted and/or removed to produce electricity, alternative fuels, chemicals, or other products that meet quality standards for use in the marketplace, with a minimum amount of residuals remaining after processing.”
Option 3 (Findings): “Diversion credit shall be available if the Board makes the following findings: (1) the jurisdiction continues to implement the recycling and diversion programs in the jurisdiction’s source reduction and recycling element or its modified annual report; (2) the facility complements the existing recycling and diversion infrastructure and is converting solid waste that was previously disposed; (3) the facility maintains or enhances environmental benefits; and (4) the facility maintains or enhances the economic sustainability of the integrated waste management system.”
Option 4 (Report): “Beginning in 3 years after a conversion facility is permitted by the CIWMB and is operational, the Board shall, in its annual report to the Legislature, summarize the status of the conversion industry, including a list of permitted facilities and their contribution to the diversion of materials from landfills.”
Option 5C (Level of Diversion Credit): "Jurisdictions that meet all of the above criteria [i.e., the findings by the Board] will be eligible for 10 percent diversion credit. Three years after a conversion facility is permitted by the CIWMB and is operational, the Board shall annually evaluate the amount of diversion credit that can be claimed by a jurisdiction, on a case-by-case basis, that sends materials to that facility. As part of its annual report to the Legislature in 2005, the Board should evaluate the effects of allowing diversion credit for conversion technologies and provide recommendations on whether the level of diversion credit should be increased as part of the AB 939 framework."

The adopted policies would need some clarification, but they seem to require continuation of all existing and planned diversion programs, as well as seem to allow diversion credit for only that waste that was previously disposed. Option 5C would allow for 10 percent diversion credit and leaves open the possibility of more diversion credit in the future.

Finding #14: Impacts on recycling and organics markets will be significantly influenced by CIWMB policy on diversion credit for conversion technology facilities.

The financial model was run to estimate the impact on revenues, tons, and jobs in the recycling and organics markets under the following scenarios:

Scenario 1. No diversion credit for conversion technology (as described earlier in this chapter under Finding #1.) This is the base case scenario. The facility configurations are described in Chapter 1. The results of the model runs are presented below under Summary of Model Results, and the full model for Scenario 1 appears in Appendix F.

Scenario 2A. Conversion technology diversion credit is given for refuse that is currently disposed. Jurisdictions would make no changes to existing diversion programs.

Scenario 2B. Conversion technology diversion credit is given for refuse currently disposed, capped at a maximum 10 percent credit per jurisdiction. Jurisdictions would make no changes to existing diversion programs.

Scenario 3. Conversion technology diversion credit for any material delivered to conversion technology facilities. This scenario assumes all residential material (refuse, recyclables, and green waste) is sent to conversion technology facilities. Jurisdictions could realize significant collection cost savings by collecting all materials with a single truck.

Scenario 4. Conversion technology diversion credit for any material delivered to conversion technology facilities. This scenario assumes all residential refuse and residential green waste will be sent to conversion technology facilities. Jurisdictions could realize significant collection cost savings by collecting refuse and green waste materials with a single truck.

A detailed description of each of these scenarios and their results are provided in Appendix F. Summary results are provided in Table 42 for the Greater Los Angeles region and Table 43 or the San Francisco Bay region.

Summary of Model Results

Finding #15: Scenario 1 Results. Preparing feedstock for use in conversion technology facilities generates additional recycling-related jobs for additional MRF sorters and jobs in the recovered-materials industry. For the purpose of determining the number of jobs potentially generated, we assumed that facilities were operating at the capacities listed in Table 40.

For the purposes of calculating jobs, we used average figures. Although an overall relationship between tons and jobs is generally true for the industry as a whole, a perfect linear relationship does not exist. Different facilities have variances in economies of scale, as well as different operating procedures. Also, when tonnage is gained or lost, certain fixed positions cannot be eliminated or added quickly. Table 40 summarizes resulting jobs for the Greater Los Angeles region and the San Francisco Bay region, respectively.

Additional Materials Recovery Facility Sorting Positions

Feedstock must be sorted in a specific manner prior to use in any of the three types of conversion technology facilities reviewed in this study. Whether or not this material includes residuals from MRFs, this material must be sorted in a specialized way and will require additional sorters to remove recyclables and contaminants.

Feedstock for catalytic cracking facilities would not need to be sorted on a separate facility line. Catalytic cracking facilities would accept only film plastic, which could be sorted from an existing MRF line that is already sorting clean recyclables or mixed waste. It would also require additional workers on existing sorting lines.

R.W. Beck, Inc., determined in the *U.S. Recycling Economic Information Study* (July 2001) that, based on the MRFs studied, a cumulative annual throughput of 3,625,000 tons at a MRF resulted in 2,606 jobs, or a ratio of 0.72 jobs per 1,000 tons of annual throughput.

Whether the new positions are at an existing facility or on a line established specifically for conversion technology sorting, increased sorting will translate to increased workers needed. Using R.W. Beck's ratio, acid hydrolysis sorting requirements could add from 64 to 121 sorting jobs in each region over the term of this study. Gasification sorting needs could add from 45 to almost 82 positions in each region. Sorting out the additional film plastic for catalytic cracking could add 12 positions in each region.

Additional Recovered Material

This additional sorting of acid hydrolysis and gasification feedstock will result in the recovery of additional recyclable materials. When these materials are recycled back into the market for remanufacturing, additional jobs could be created relating to the use of this recovered material, as shown in Table 40.

Table 40. Scenario 1– Additional Material Diverted and Jobs Potentially Created Through Sorting of Feedstock for Conversion Technology Facilities

Material	Jobs per 1,000 Tons[a]	Tons—2003[b]	Additional Jobs—2003	Tons—2010[b]	Additional Jobs—2010
Greater Los Angeles Region—Acid Hydrolysis					
Plastic	77.1	36,109	2,784	61,353	4,730
Glass	5.0	17,960	90	28,946	145
Metal	8.3	35,778	297	57,656	479
MRF	0.72	89,847	65	147,955	107
Total			3,236		5,461
San Francisco Bay Region—Acid Hydrolysis					
Plastic	77.1	34,784	2,682	59,419	4,581
Glass	5.0	18,628	93	31,050	155
Metal	8.3	46,208	384	77,223	641
MRF	0.72	99,620	72	167,692	121
Total			3,231		5,498
Greater Los Angeles Region– Gasification					
Glass	5.0	21,024	105	30,423	152
Metal	8.3	41,882	348	60,599	503
MRF	0.72	62,906	45	91,022	66
Total			498		721
San Francisco Bay Region – Gasification					
Glass	5.0	21,904	110	32,763	164
Metal	8.3	54,334	451	81,483	676
MRF	0.72	76,238	55	114,246	82
Total			616		922
Greater Los Angeles Region - Catalytic Cracking					
MRF—Sorting of film plastics	0.72	16,450	12	16,450	12
San Francisco Bay Region - Catalytic Cracking					
MRF—Sorting of film plastics	0.72	16,450	12	16,450	12

[a] Calculated using jobs per ton factors in the *U.S. Recycling Economic Information Study*, R. W. Beck, Inc., July 2001. This table does not include landfill or conversion technology facility jobs.
[b] Assumes conversion technology facilities are operating at full capacity under proposed configurations. See Table 4 for tonnage.

Conversion Technology Facility Jobs

Additional workers would be employed to operate conversion technology facilities. Using a rough estimate from the projected number of jobs at the Masada plant under construction, conversion technology facilities will generate 0.76 jobs per 1,000 tons of throughput. It is not clear how many of these jobs are sorting jobs.

Landfill Job Losses

Conversion technology facilities would decrease the amount of waste disposed in landfills, which would result in a net loss in revenues to landfills. Decreases in tonnage and revenues to landfill may result in job losses at landfills.

Finding #16: Scenario 2A and Scenario 2B Results.

Scenario 2A and Scenario 2B both assume only material destined for landfilling is redirected to conversion technology facilities. Sufficient tonnage would be available under these scenarios, provided the Greater Los Angeles region's conversion technology tipping fee did not greatly exceed $40 per ton and the San Francisco Bay region's conversion technology tipping fee did not greatly exceed $50 per ton under either scenario. Under Scenario 2A, in the Greater Los Angeles region, the demand for conversion technology facilities would exceed available conversion technology facility capacity. However, under Scenario 2B, the demand would only be for around 72 percent of the available capacity. In the San Francisco Bay region, the tonnage demand was estimated at 62.5 percent and 40 percent of available capacity for Scenario 2A and Scenario 2B, respectively.

Both scenarios would provide increased recycling market revenue, jobs, and tonnage. Increased revenue could be as high as $171 million to $400 million per region per year over the study term. Additional jobs could be from 1,500 to 3,600 per region over the study term. Additional recycling tonnage would be 70,000 to 153,000 per region per year over the study term.

Landfill revenue, tonnage, and jobs would decrease under all scenarios.

Finding #17: Scenario 3 Results.

Scenario 3 assumes that cities discontinue their three stream (source-separated recyclables, organics, and refuse) collection systems and send the resulting mixed residential refuse to conversion technology facilities. This would be motivated by allowing diversion credit for material sent to conversion technology. This scenario assumes the gasification and acid hydrolysis facilities operate at full capacity.

Under Scenario 3, more than 500,000 fewer tons in each region may be available to the recyclables and organics markets. The materials recovered would be plastic, metal, and glass. Paper and organics, which comprise the majority of the recyclable materials present in the feedstock, would not be recovered.

Far fewer tons of recyclables would be recovered through presorting than if the recyclables and organics were separated and sent to other processing facilities. But the effect on recyclables revenue and recyclables job creation may still be positive. According to ratios based on data from the *U.S. Recycling Economic Information Study*, organics and paper generate far fewer jobs and less revenue per ton than plastics. A combination of the recyclables recovered from the refuse is sent to conversion technology. Because of the plastic that is recovered through the gasification process, the revenue and job effect on the recyclables industry is slightly positive. However, if the plastic industry ratios were similar to levels found for other recyclables, the effect on the recyclables industry would be negative in all categories.

The net effect on organics markets would be a decrease in approximately 76 jobs in each region and $7 million to $10 million in annual revenue for the organics industry per region over the study term, with approximately 364,000 of the more than 500,000 net recoverable tons lost to the conversion technology process being organics.

Finding #18: Scenario 4 Results.

Scenario 4 assumes that cities keep their source-separated recyclables programs, but discontinue their source-separated organics collection, and instead have organics and refuse collected in the same stream. This mixed waste stream would be sent to conversion technology facilities. This would be motivated by allowing diversion credit for material sent to conversion technology. This scenario assumes the gasification and acid hydrolysis facilities operate at full capacity.

For example, under Scenario 4 in 2003, in the Greater Los Angeles region, 399,994 fewer tons of organics may be available for use as compost, mulch, and ADC. However, more than 102,344 additional tons of recyclable materials may be recovered from this mixed feedstock. Thus, the net loss of recoverable tons may be almost 300,000 tons per year.

According to ratios based on data from the *U.S. Recycling Economic Information Study*, additional jobs created by the recyclables removed from the feedstock during the presort for the conversion technology facility would dwarf the number lost in the organics industry. This figure includes 2,400 to 4,200 recycling jobs over the study term, compared to a loss of 84 organics jobs. However, this is partially due to a high number of jobs per ton calculated for the plastics industry. The jobs created are due to sorting the refuse portion of the materials sent to conversion technology facilities, not the organics portion. The effect of sending organics to conversion technology facilities does not generate jobs for the recycling industry.

Over the study term, revenue loss to the organics industry could be $8 million to $11 million per region per year. The revenue increase to the recycling industry could be significantly higher, $292 to $620 million per year over the study term, depending upon the region.

Table 41 and Table 42 (one for each region) summarize the results from Findings 13 through 17.

Table 41. Scenario Results for the Greater Los Angeles Region

Total Tons To CT Facilities, 2003 - Greater Los Angeles Area

	Scenario 1	Senario 2A	Senario 2B	Scenario 3	Scenario 4
Diverted from Landfills	1,367,857	1,367,857	1,176,356	683,928	916,464
Diverted From Recycling Facilities	-	-	-	262,783	-
Diverted From Green Waste Facilities	-	-	-	363,631	399,994
Total To CT Facilities	1,367,857	1,367,857	1,176,356	1,310,342	1,316,458
Recyclables Removed	152,753	152,753	131,368	108,861	102,344
Contaminants Removed	76,282	76,282	65,602	57,966	71,109
Processed Through CT (1)	1,138,822	1,138,822	979,386	1,143,515	1,143,005

Impact on Recycling and Organics Markets, 2003 - Greater Los Angeles Area

	Scenario 1	Senario 2A	Senario 2B	Scenario 3	Scenario 4
	CTs at maximum capacity using LF tons as feedstock	D.C. for Refuse to CT to Meet 50% Diversion Goal	D.C. for Refuse to CT to Meet 50% Diversion with 10% cap	D.C. for all solid waste all res to CT	D.C. for all solid waste Res Refuse and Green Waste CT
Recycling Markets					
Revenue Increase (Decrease)	$ 436,167,031	$ 436,167,031	$ 375,106,586	$ 30,983,764	$ 292,231,435
Jobs Increase (Decrease)	3,630	3,630	3,121	491	$ 2,432
Tons Increase (Decrease)	152,753	152,753	131,368	(153,922)	$ 102,344
Organics Markets					
Revenue Increase (Decrease)	$ -	$ -	$ -	$ (7,232,621)	$ (7,955,881)
Jobs Increase (Decrease)	-	-	-	(76)	$ (84)
Tons Increase (Decrease)	-	-	-	(363,631)	$ (399,994)

Total Tons To CT Facilities, 2010 - Greater Los Angeles Area

	Scenario 1	Senario 2A	Senario 2B	Scenario 3	Scenario 4
Diverted from Landfills	2,151,060	2,151,060	1,548,764	1,075,530	1,441,210
Diverted From Recycling Facilities	-	-	-	414,260	-
Diverted From Green Waste Facilities	-	-	-	571,421	628,564
Total To CT Facilities	2,151,060	2,151,060	1,546,764	2,061,211	2,069,774
Recyclables Removed	238,977	238,977	172,063	171,849	160,114
Contaminants Removed	122,541	122,541	88,228	92,429	113,530
Processed Through CT (1)	1,789,542	1,789,542	1,288,473	1,796,673	1,796,130

Impact on Recycling and Organics Markets, 2010 - Greater Los Angeles Area

	Scenario 1	Senario 2A	Senario 2B	Scenario 3	Scenario 4
	CTs at maximum capacity using LF tons as feedstock	D.C. for Refuse to CT to Meet 50% Diversion Goal	D.C. for Refuse to CT to Meet 50% Diversion with 10% cap	D.C. for all solid waste all res to CT	D.C. for all solid waste Res Refuse and Green Waste CT
Recycling Markets					
Revenue Increase (Decrease)	$ 873,691,646	$ 873,691,646	$ 751,367,273	$ 101,481,223	$ 585,366,635
Jobs Increase (Decrease)	6,018	6,018	5,176	1,011	$ 4,032
Tons Increase (Decrease)	238,977	238,977	205,520	(242,411)	$ (160,114)
Organics Markets					
Revenue Increase (Decrease)	$ -	$ -	$ -	$ (14,456,951)	$ (15,902,669)
Jobs Increase (Decrease)	-	-	-	(120)	$ (132)
Tons Increase (Decrease)	-	-	-	(571,421)	$ (628,564)

D.C. = Diversion Credit

(1) Processed through CT, net of residuals left after processing.

Table 42. Scenario Results for the San Francisco Bay Region

	Scenario 1	Scenario 2A	Scenario 2B	Scenario 3	Scenario 4
Diverted from Landfills	1,396,423	872,765	558,569	698,212	935,604
Diverted From Recycling Facilities	-	-	-	262,783	-
Diverted From Green Waste Facilities	-	-	-	363,631	399,994
Total To CT Facilities	1,396,423	872,765	558,569	1,324,626	1,335,598
Recyclables Removed	175,858	109,911	70,343	120,413	117,825
Contaminants Removed	83,155	51,973	33,262	61,402	75,715
Processed Through CT (1)	1,137,410	710,881	454,964	1,142,811	1,142,058
Impact on Recycling and Organics Markets, 2003 - San Francisco Bay Area					
	Scenario 1	Scenario 2A	Scenario 2B	Scenario 3	Scenario 4
	CTs at maximum capacity using LF tons as feedstock	D.C. for Refuse to CT to Meet 50% Diversion Goal	D.C. for Refuse to CT to Meet 50% Diversion with 10% cap	D.C. for all solid waste all res to CT	D.C. for all solid waste Res Refuse and Green Waste CT
Recycling Markets					
Revenue Increase (Decrease)	$428,660,336	$267,912,636	$171,468,406	$ 27,214,344	$287,210,262
Jobs Increase (Decrease)	3,705	2,315	1,482	528	$ 2,482
Tons Increase (Decrease)	175,858	109,911	70,343	(142,370)	$ (117,825)
Organics Markets					
Revenue Increase (Decrease)	$ -	$ -	$ -	$ (10,145,305)	$ (11,159,833)
Jobs Increase (Decrease)	-	-	-	(76)	$ (84)
Tons Increase (Decrease)	-	-	-	(363,631)	$ (399,994)
Total Tons To CT Facilities, 2010 - San Francisco Bay Area					
	Scenario 1	Scenario 2A	Scenario 2B	Scenario 3	Scenario 4
Diverted from Landfills	2,204,254	1,377,659	881,702	1,102,127	1,476,850
Diverted From Recycling Facilities	-	-	-	414,260	-
Diverted From Green Waste Facilities	-	-	-	571,421	628,564
Total To CT Facilities	2,204,254	1,377,659	881,702	2,087,808	2,105,414
Recyclables Removed	281,938	176,211	112,775	193,331	188,899
Contaminants Removed	135,730	84,833	54,293	99,023	122,367
Processed Through CT (1)	1,786,586	1,116,615	714,634	1,795,454	1,794,148
Impact on Recycling and Organics Markets, 2010 - San Francisco Bay Area					
	Scenario 1	Scenario 2A	Scenario 2B	Scenario 3	Scenario 4
Recycling Markets					
Revenue Increase (Decrease)	$924,672,794	$577,922,123	$369,874,552	$103,369,063	$619,534,694
Jobs Increase (Decrease)	6,194	3,872	2,478	1,099	$ 4,150
Tons Increase (Decrease)	281,938	176,211	112,775	(220,929)	$ 188,899
Organics Markets					
Revenue Increase (Decrease)	$ -	$ -	$ -	$ (20,285,446)	$ (22,314,022)
Jobs Increase (Decrease)	-	-	-	(120)	$ (132)
Tons Increase (Decrease)	-	-	-	(571,421)	$ (628,564)
D.C. = Diversion Credit					

Limitations Of Results Presented

Technology

Making estimates about conversion technology pricing (tipping fees) and feedstock is speculative because no commercial scale facilities currently exist in California. The findings presented in this chapter are dependent upon the assumptions that were listed herein. Actual conversion technology tipping fees, tonnages accepted, and feedstock requirements may be very different than our assumptions, and would therefore produce different results.

Our assumptions included specific numbers of facilities, using a specific combination of conversion technologies provided by the CIWMB. Actual facility implementation may be very different from these assumptions, and the resulting impacts on markets will vary from our findings.

Advances in conversion technologies and capabilities and advances in sorting technologies would likely reduce the conversion technology cost structure. If those reduced costs were reflected in facility tipping fees, it could have very different results on the recycling and compost markets.

Market Conditions

In historical terms, recycling markets are currently experiencing a period of high demand and high prices. The markets have been very volatile in the past and will likely experience extreme volatility in the future. The impact of China has been emphasized in this chapter, but exactly when or if China will be able to develop sufficient material sources within Asia to reduce demand in the United States is unknown. The United States may experience periods of extremely low recycling demand or prices in the future, and this would cause results very different from the results presented in this chapter.

Impacts on Markets Regardless of Price

It remains to be seen what arrangements will be made with regard to facility ownership and how this might encourage or forestall conversion technology development. If conversion technologies are fully embraced by national or regional waste-hauling companies, they may be utilized to a greater extent than market prices would dictate in order to keep facilities operating. Municipally owned facilities, if any are developed, might have similar incentives to operate at higher capacities than market prices would dictate.

Typical Firm

Although the results presented herein refer to the markets as a whole, the impacts on any individual firm are far more dependent on local conditions, local contracts, and management of the firm. This is especially true for smaller or more regional firms. The larger firms will have experiences that are more similar to the market as a whole. In addition, any conversion technology facilities that are sited and accept materials will have an impact on other facilities in the immediate area (within 15 to 40 miles.)

Chapter 7 Future Research Needs

In this chapter, we identify and summarize what we feel to be key areas for future research with respect to conversion technologies and their potential life cycle and market impacts. An overview of these key areas is as follows:

- **Update the results from the study with environmental and operating data from actual facilities in California and the United States.** In conducting the study, no data were available for conversion technologies operating in the United States. This is because none of the conversion technologies included in the study are currently operating in the United States. Therefore, we relied largely on vendor-supplied information, permit applications, and international information for constructing the life cycle and market impact information for each technology. We expect new conversion technology facilities to become operational in the near future, both in the State of California and in other states.
- **Analysis of regions with different waste compositions.** In this study, we analyzed two regions: Los Angeles and San Francisco. These two regions are both urban and have very similar compositions of waste disposed. Therefore, the results of the study for the two regions are very similar. Analyzing the conversion technologies in the context of a very different waste composition and different market economics and evaluating how the results of the life cycle study might change would be useful. Results are significantly different from a market-impact perspective.
- **Analysis of other feasible conversion technologies.** The CIWMB defined three specific conversion technologies for the team to investigate in the life cycle and market impact studies. Concurrently, the University of California was performing a companion study to evaluate the world of conversion technologies and their feasibility for near-term implementation. Some technologies may be quite different from the three specific technologies included in this study. Similarly, the three technologies have a wide range of practice. For example, we could have studied a fairly wide variety of gasification systems. We studied one particular technology that most closely met the State's definition of gasification.
- **Analysis of optimal conversion technology facility configurations**. The CIWMB defined specific configurations and capacities for the hypothetical conversion technology scenario included in this study. We did not evaluate aspects such as optimal co-location of conversion technologies with existing waste management facilities or the optimal mix of conversion technologies given a defined quantity and composition of waste.
- **Investigation of the market impacts of handling other wastes through conversion technologies versus the currently available technologies of landfilling, recycling, and composting.** While drafting this report, we received several comments about waste streams such as agricultural waste, biosolids, and wood waste, and their potential viability for CT feedstock. These wastes are generally outside of the purview of the CIWMB, however, changes in regulations, especially air quality regulations, may cause these wastes to be landfilled in the future, which would bring them into the purview of the CIWMB. The CIWMB may want to investigate the market impacts of handling these wastes through conversion technologies versus the currently available technologies of landfilling, recycling, and composting.

- **Research into conversion factors for plastics.** The available economic information for plastics (tons to jobs and revenue conversion factors) seem to be overly inflated compared to the other factors for other materials. This results in high estimates of economic impacts of recycling and may generally skew the study results. Further research into the plastics conversion factors may result in more accurate results, if the plastics data is found to be incorrect.
- **Research into the study findings related to the impact of China on the demand for recycled materials.** China's demand for recycled materials from California are significant, not just to this study, but to California's entire recycling infrastructure. The high recycling rates California has experienced will likely continue as a result of program implementation coupled with high demand for recyclable materials. Some predict that China will be able to supply its own demand for recyclable materials in the next 10 to 20 years. If so, this would have large impacts on California's recycling infrastructure in the future. This is an issue that the CIWMB should revisit in future years as part of its ongoing strategic planning process.
- **Analysis of the impact of small modular conversion technology facilities.** This study focused on larger regional facilities located in urban areas with access to a large waste stream. Several comments received through the public comments referred to smaller, more modular facilities. These facilities would experience similar economics on a per-ton basis, but they might be able to provide unique solutions, especially in less urban areas. These facilities might provide both a waste solution and an energy solution to a community, a manufacturing facility, or a farm. The CIWMB might want to explore the impacts of this type of scenarios for conversion technologies.

Abbreviations and Acronyms

AB: assembly bill

ADC: alternative daily cover

BIGCC: biomass integrated gasifier combined cycle

CAI: Combustion Associates International

CO: carbon monoxide

CO_2: carbon dioxide

CRV: California redemption value

CT: conversion technology

CWIMB: California Integrated Waste Management Board

U.S. EPA: U.S. Environmental Protection Agency

H_2: hydrogen

HAP: hazardous air pollutant

HDPE: high density polyethylene

ISBL: inside battery limits

ITEQ: international toxic equivalent

kW: kilowatt

LCA: life cycle assessment

LCI: life cycle inventory analysis

LDPE: low density polyethylene

MIA: market impact assessment

MW: megawatt

MRF: materials recovery facility

MSW: municipal solid waste

MSW DST: RTI's Municipal Solid Waste Decision Support Tool

NO_x: nitrogen oxides

PE: polyethylene

PE-L: melted polyethylene

PET: polyethylene terephthalate.

POTW: publicly owned treatment works

PP: polypropylene

PP-L: melted polypropylene

PS: polystyrene

PS-L: melted polystyrene

PVC: polyvinyl chloride

RDF: refuse derived fuel

SCR: selective catalytic reduction

SWERF: Solid Waste Energy Recycling Facility

SO_x: sulfur oxides

SWIS: Solid Waste Information System

TCI: total capital investment

TCLP: toxicity characteristics and leaching procedure

TIC: total installed capital

tpd: tons per day

tpy: tons per year

VOC: volatile organic compound

WTE: waste-to-energy

Glossary of Terms

Allocation: Technique for partitioning multiple inputs and outputs from a system.

Chemical pulp: Pulp obtained by digestion of wood with solutions of various chemicals. The paper produced is strong and less prone to discoloration. The pulp yield is lower in this process. The principal chemical processes are the sulfate (kraft), sulfite, and soda processes. Chemical pulps are used to make shipping containers, paper bags, printing papers, writing papers, and other products requiring strength. (Pre- and post-consumer material)

Corrugated container: A box in its most common form is manufactured from containerboard, layers of linerboard and one layer of medium. The layers are combined in a corrugator, a machine that presses corrugations into the medium and laminates a layer of linerboard to each side. The sheets are folded, printed, and glued or stapled to make a finished box (post-consumer material).

Data Quality Indicator: Measure that characterizes an attribute(s) of data or data sets.

Deinking: A process in which most of the ink, filler, and other extraneous material is removed from printed and/or unprinted recovered paper. The result is a pulp that can be used, along with varying percentages of wood pulp, in the manufacture of new paper, including printing, writing and office papers, as well as tissue (postconsumer material).

Function: Performance characteristic of a system.

Functional Unit: Measure of performance of the main functional output of a system.

Integrated Waste Management: Interlinked stages of a system to collect, process, treat, and dispose of waste.

Life Cycle: Consecutive and interlinked stages of a system that extend from raw materials acquisition or generation of natural resources to final disposal.

Life Cycle Assessment: Compilation and evaluation, according to a systematic set of procedures, of the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the function of a product throughout its life cycle.

Life Cycle Impact Assessment: Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of environmental impacts based on a life cycle inventory analysis.

Life Cycle Inventory Analysis: Phase of life cycle assessment involving compilation and quantification of inputs and outputs for a given product system throughout its life cycle.

Mechanical pulp: Any wood pulp manufactured wholly or in part by a mechanical process, including stone-ground wood, chemigroundwood, and chip mechanical pulp. Paper made by this process is opaque and has good printing properties, but is weak and discolors easily when exposed to light due to residual lignin in the pulp. Uses include newsprint, printing papers, specialty papers, tissue, toweling, paperboard, and wallboard (pre- and postconsumer material).

Mixed paper: Mixture of all paper grades, to be sorted at the destination (postconsumer material).

Municipal Solid Waste: Waste generated in the residential, multifamily, and commercial sectors. Includes durable goods, nondurable goods, containers and packaging, food waste, and yard trimmings. Also includes ash from waste combustion. Excludes industrial process waste, sludge, construction and demolition waste, pathological waste, agricultural waste, mining waste and hazardous waste.

Newsprint: A lightweight paper made mainly from mechanical wood pulp, engineered to be bright and opaque for the good print contrast needed by newspapers. Newsprint also contains special tensile strength for repeated folding. It does not include printing papers of types generally used for purposes other than newspapers, such as groundwood printing papers for catalogs or directories (postconsumer material).

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